Globalization of Aerospace Propulsion Research – India at Crossroads

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INDIA

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Busan, Korea

- India initiated economic liberalization in 1992 (open market economy).

- Various Indian Institutes started global collaboration in science and Technology research by 1995

- Norms and Rules on IP sharing and joint Patenting by various Institutes have been framed by the year 2000

Various Indian Institutes for global aerospace research collaboration:

1) **Indian Institutes of Technology:**
   - **Madras**
   - **Kanpur**
   - **Bombay**

2) **Indian Institute of Science, Bangalore**

3) **National Aerospace Laboratory, Bangalore**

4) **Indian Space Research Organization (ISRO)**

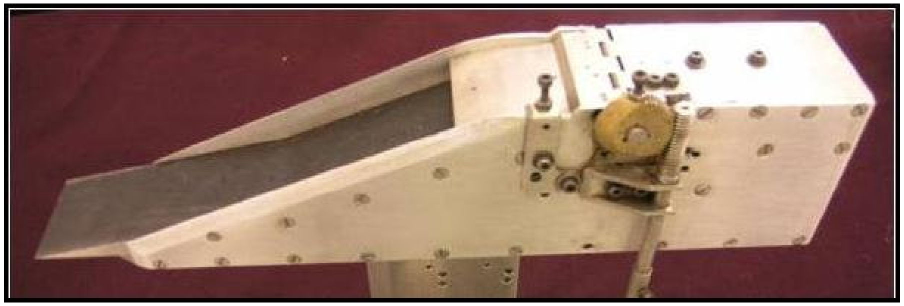
AIR BREATHING PROPULSION AT ISRO
SCRAMJET ENGINE DEVELOPMENT

- As part of ISRO's efforts to master high speed Air Breathing Propulsion, scramjet engines capable of supersonic combustion of fuel and atmospheric air being developed

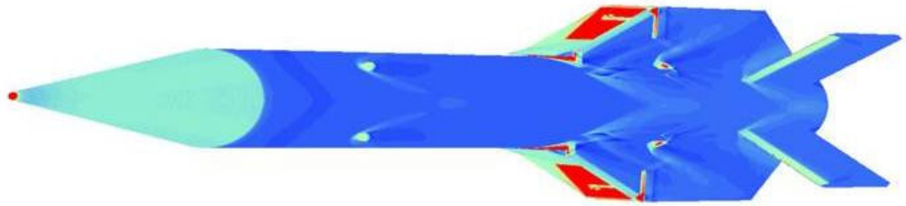
- Complex air intakes are used to collect atmospheric air for scramjet operation while flying at hypersonic speeds

- Detailed CFD analyses are carried out from nose-tip to nozzle-end including simulation of air-fuel combustion for full engine performance evaluation

A test combustor successfully used to establish supersonic combustion under ground testing



Sub scale model used for wind tunnel testing to evaluate performance of a high speed air intake



A typical 'nose-tip to nozzle-end' pressure distribution captured by CFD simulation

AIR BREATHING PROPULSION AT ISRO: FLIGHT TESTING

- To demonstrate supersonic combustion in flight, development of scramjet engine is progressing at ISRO

- A unique sounding rocket is developed to serve as flying test bed capable of providing hypersonic speeds at required low atmospheric and near horizontal flight conditions

- Real Time Decisions (RTD) are implemented to achieve this special requirement

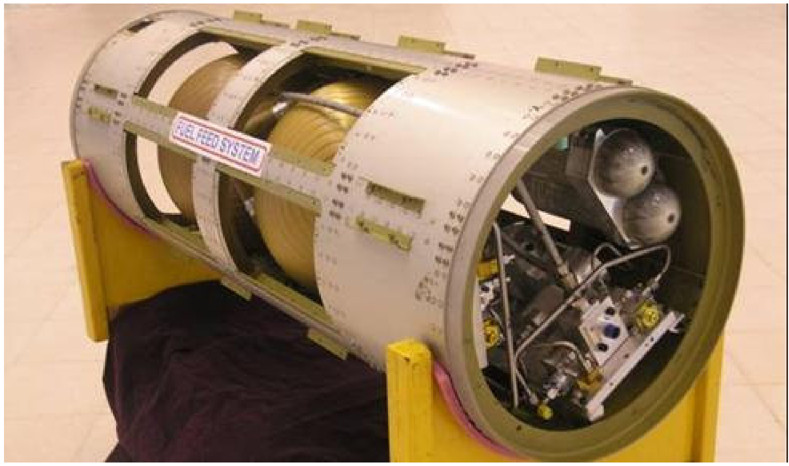
- Scramjet engines are attached to the rear of 2nd stage of the rocket, symmetrically on either side

Successful flight test from SDSC, SHAR of a rocket developed as flying test bed for air breathing propulsion

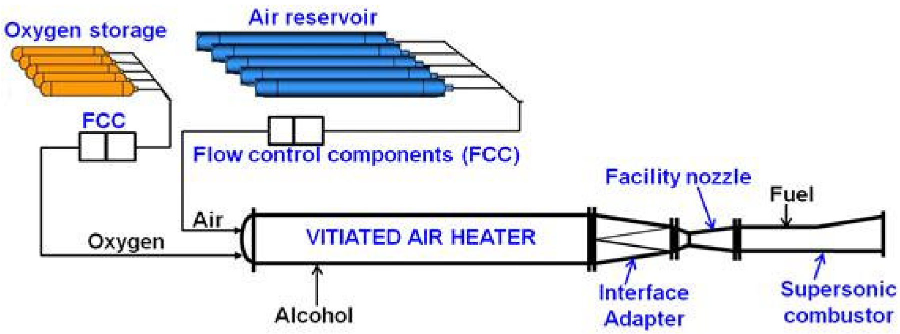
AIR BREATHING PROPULSION AT ISRO: FUEL FEED & GROUND TEST FACILITIES

- Gaseous fuel is stored during flight testing under high pressure. It is fed into supersonic combustion chambers after pressure regulation & flow metering. Also carried is small quantity of oxygen for the purpose of flame ignition

- For scaled-up studies of supersonic combustor, ground testing of bigger combustors (than that envisaged for flight demonstration) is planned. Ground facilities simulating high stagnation temperatures, pressures and flow rates representing flight Mach numbers of about eight are being established at LPSC, Mahendragiri



A Fuel Feed System which can be positioned in the fore-end of rocket to store and feed fuel to combustion chambers



Connected pipe mode testing scheme for supersonic combustion chambers using vitiated air heater with oxygen replenishment

Aerodynamics

Trisonic tunnels
Model design, fabrication, calibration & testing
Flow diagnostics, Aero acoustics

Propulsion

Combustion
Heat transfer
Turbomachinery D&T
Cascade tunnel
P&W gas turbine test rigs

Meteorology & Energy

Parallel processing systems
Meteorological modeling & SW
Wind turbines
Wind surveys and measurements
Solar energy

Computational Fluid Dynamics

External flows – subsonic to hypersonic
Internal flows
Hydro dynamics

Civil Aircraft Design & Dev.

Design, mfg, testing & certification
HANSA, SARAS
Related technologies

Electronics, Flight Mech & Controls

Control laws
Multi sensor data fusion
System identification & parameter estimation
Avionics suite
Active noise control
FOQA, ATM
Signal processing

Special Facilities

Acoustic test facility, Electro – magnetic laboratory
Flight simulators, CVI facility for ceramic composites
National facility for rolling element bearings
Integrated facility for carbon fibers and prepregs
Glass fabric prepregs, Material characterisation & testing

Electromagnetics

EM design and characterization
Radome design
Computational EM

CSIR - NAL

NAL 1959-2009

Composites

Design, Fabn, repair tech
Fibers & prepregs
Autoclaves
Non – Dest. Evaln
Structural health monitoring

Materials Science

Ceramic materials / comp.
Surface eng/ coatings
Thermo electrics
Smart materials
Airport instrumentation

Structural Technology

Structural design & analysis.
Aeroelasticity & vibration
Crash and impact
Smart structures and systems

Fatigue & Fracture

Failure & accident investigation
Full scale testing
Life extension
Damage tolerance

Propulsion

- Combustion
- Heat transfer
- Turbomachinery
- Cascade tunnel
- P&W gas turbine test rigs

NAL 1959-2009

Aeroelastic Testing of Aerospace Structures

LCA Transonic Buffet Model

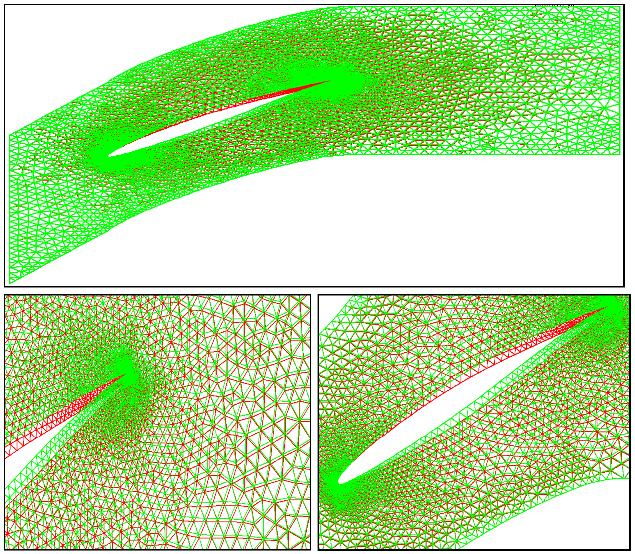
NAL is a leading national player in aeroelastic testing of aircraft and launch vehicles

1/10 scaled aeroelastic model of SARAS T-Tail at NAL

1/42 GSLV Mk3 Model

NAL 1959-2009

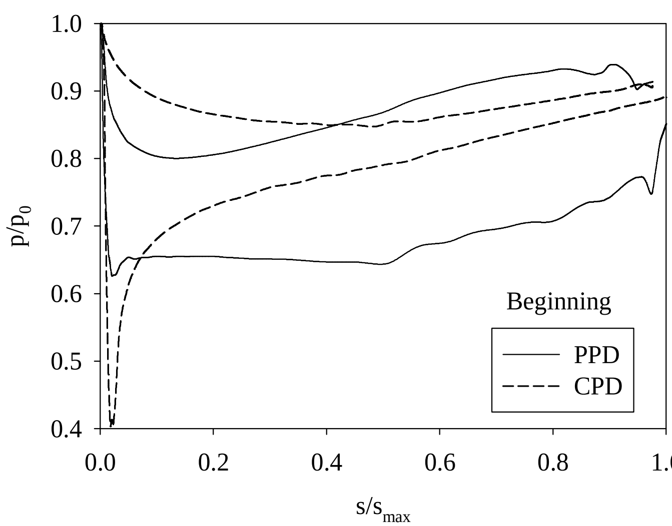
INVERSE DESIGN OF COMPRESSOR CASADE

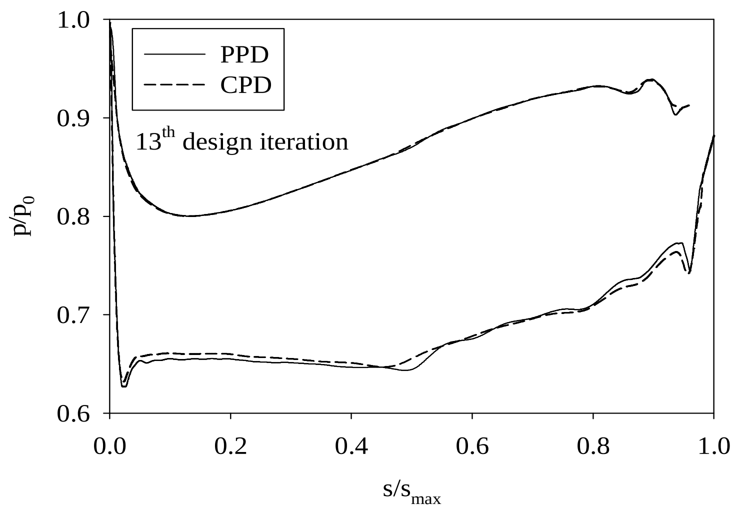


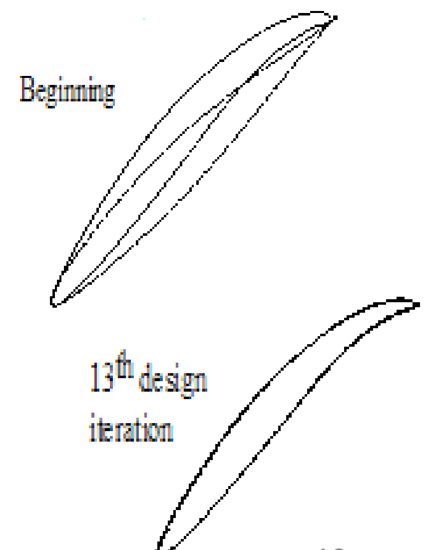
- **An inverse design code with static pressure distribution as the prescribed input is developed.**

- **An In-house code is developed based on AUSM$^+$-up scheme (*Advection Upstream Splitting Method*) which was specifically modified at low Mach number flows for flux calculation in the inverse design process.**

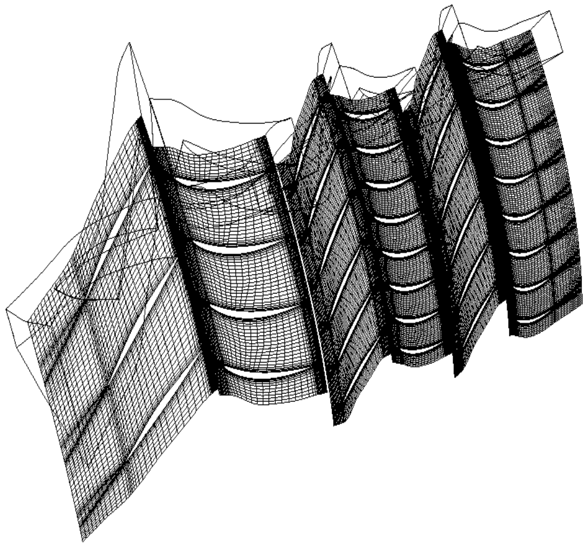
- **Further, the effect of the initial guess profiles on the final blade shape is studied.**



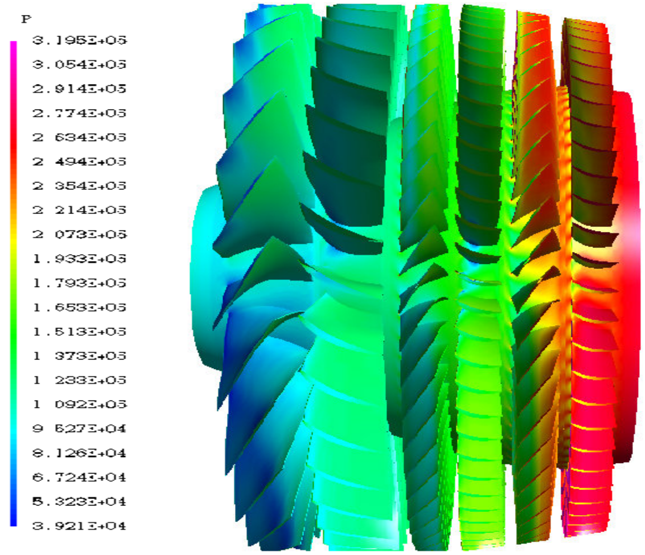




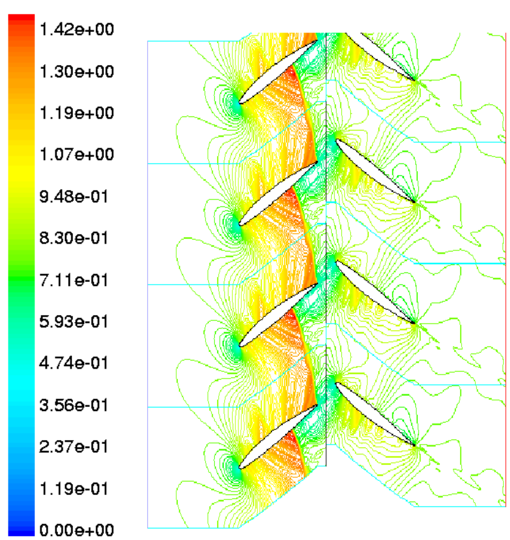
CFD STUDIES ON ROTOR-STATOR INTERACTIONS



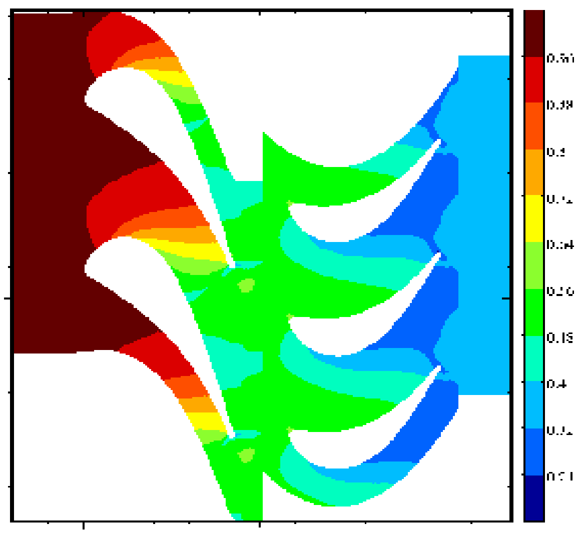
Network Representation of flow path

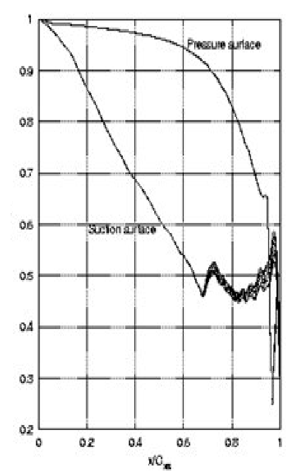


Unsteady pressure envelope

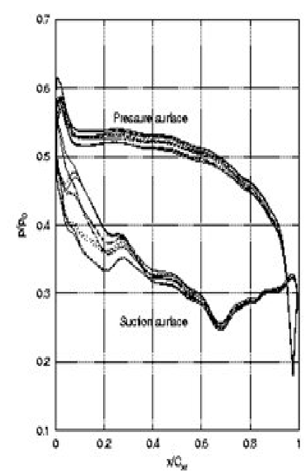


MACH CONTOURS



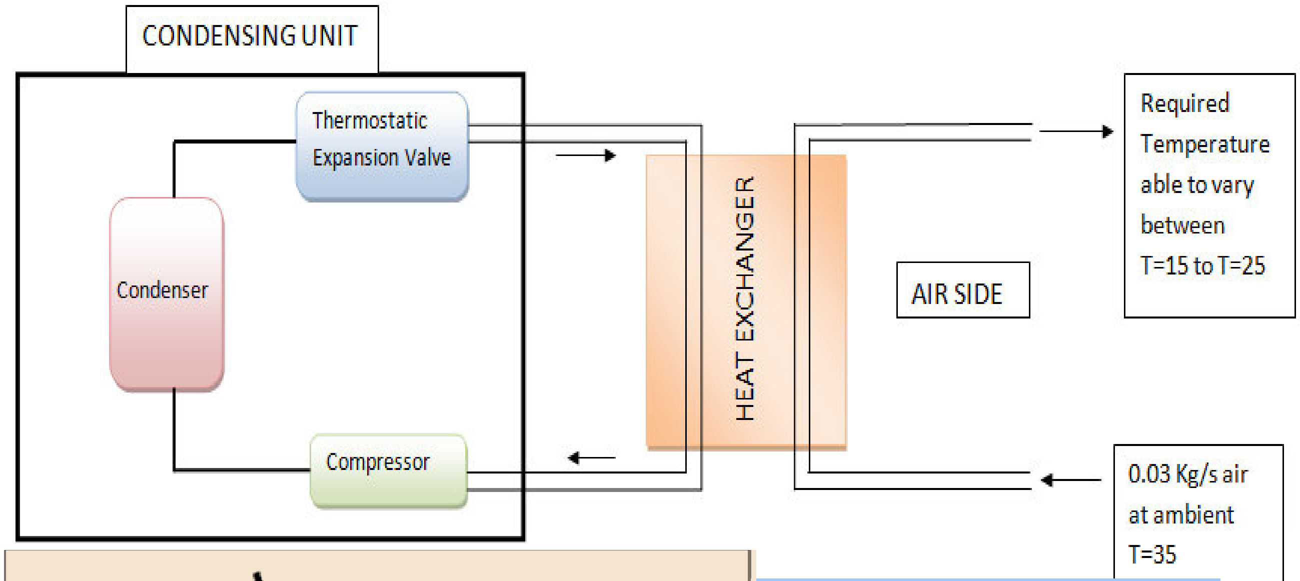


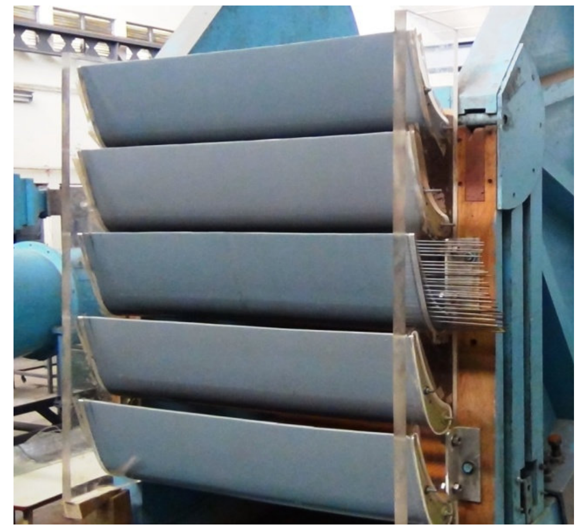
Stator

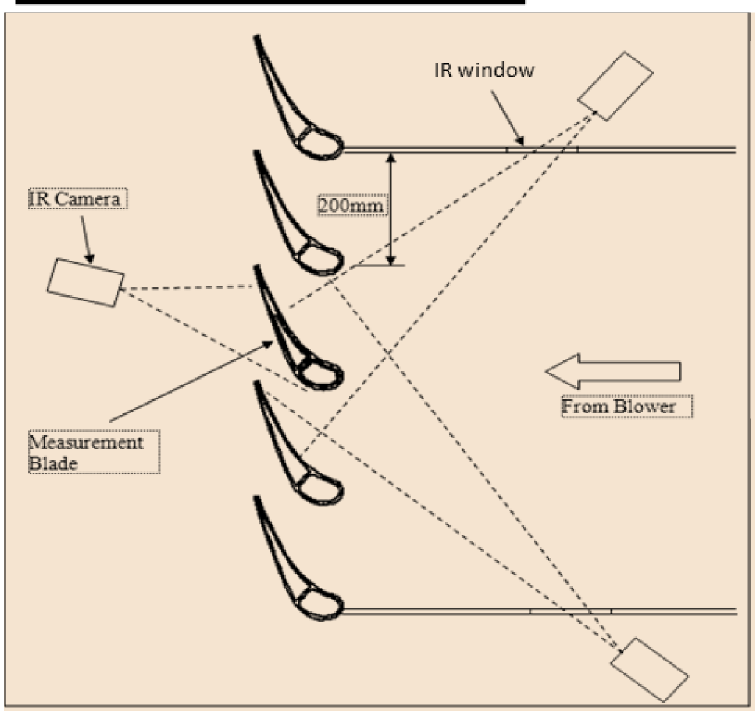


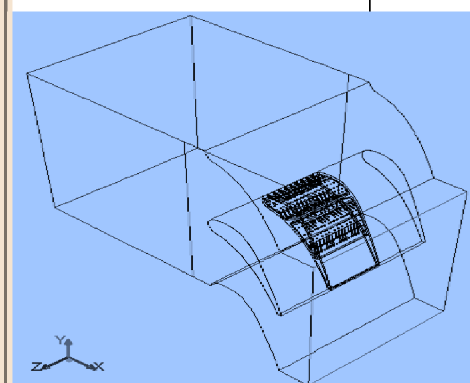
Rotor

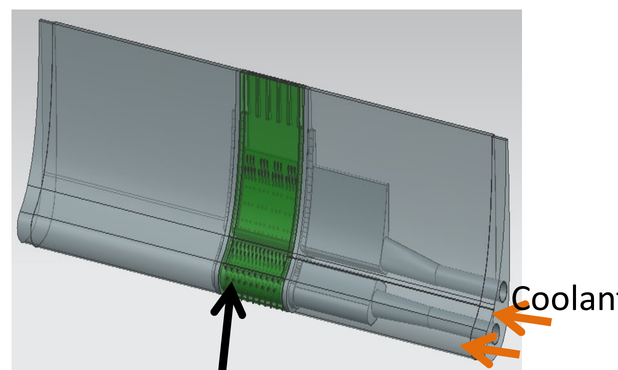
GAS TURBINE BLADE COOLING EXPERIMENTS



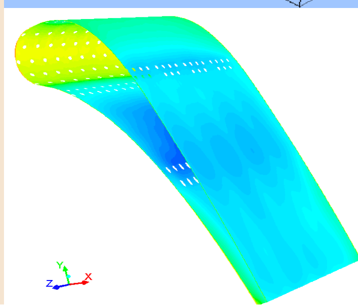








Stainless steel blade



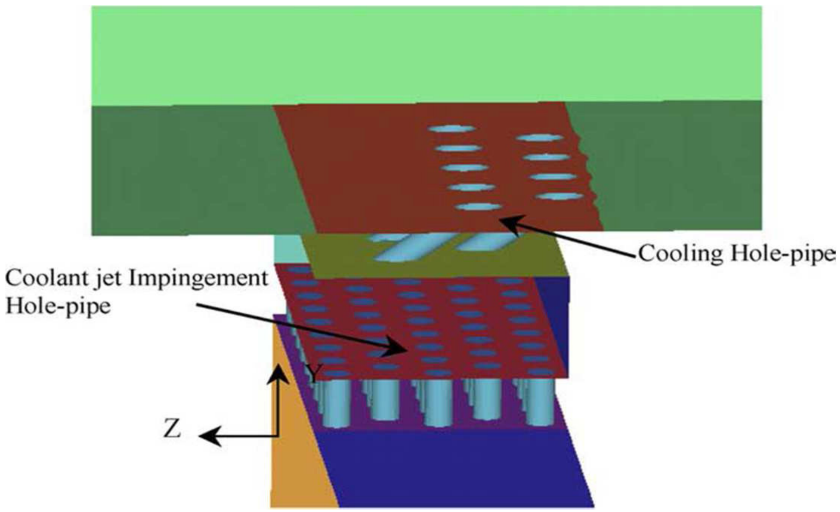
Test section

cross section : 800x800mm;

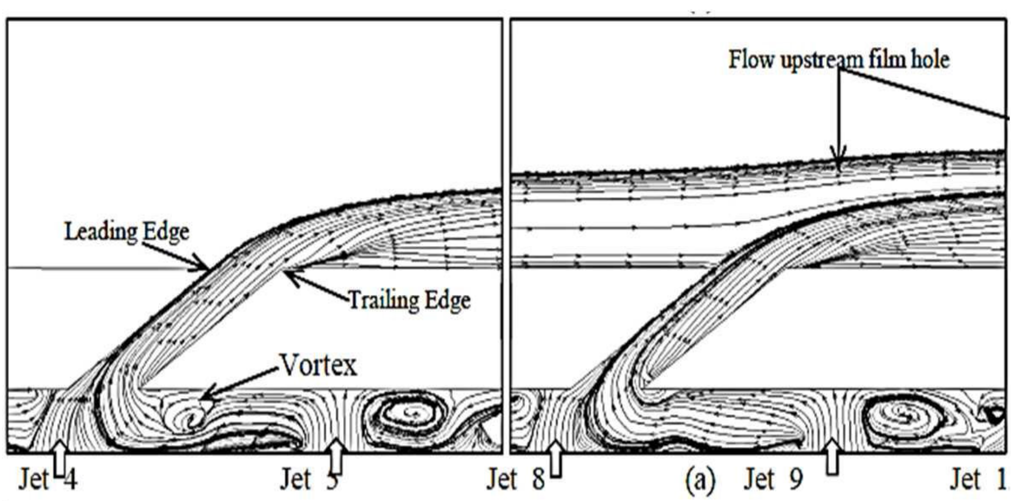
Blade pitch: 200mm;

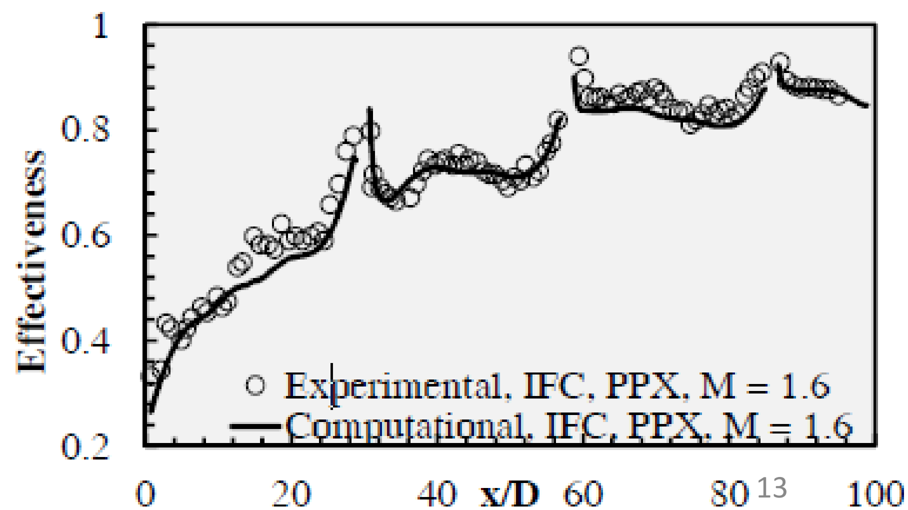
flow rate: $14 m^3/s$

Combined Impingement and Film Cooling

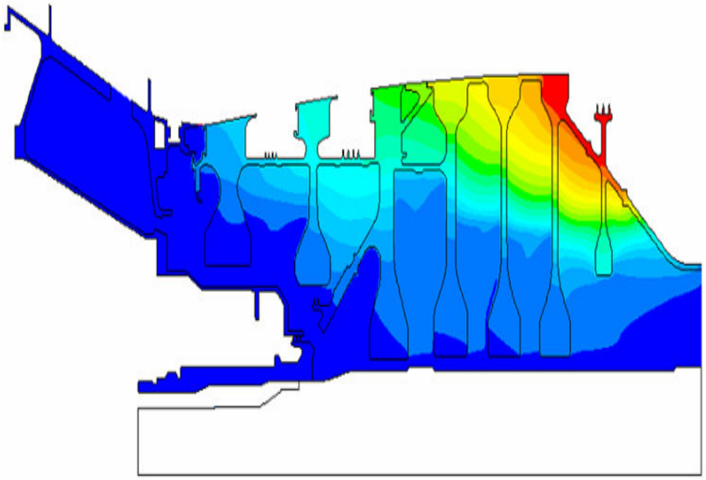


TLC Measurements





SECONDARY AIR SYSTEM ANALYSIS

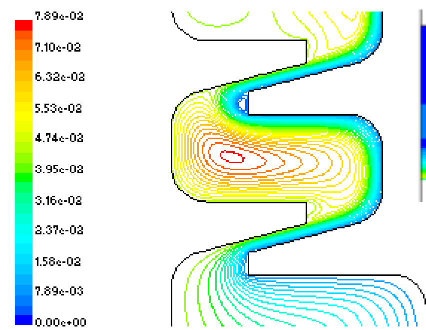


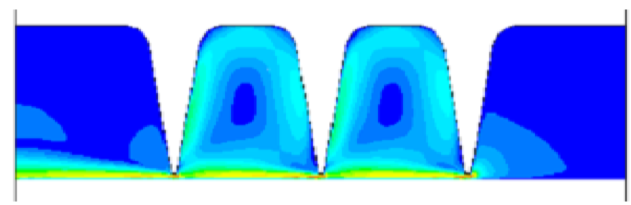
Temperature contours in the compressor disc cavities

✓**The cooling air of an aero-engine which is bled off the main gas flow in the high-pressure compressor enters on the way to the hot parts of the turbine rotating cavities located between the discs, the rim and the low-pressure shaft.**

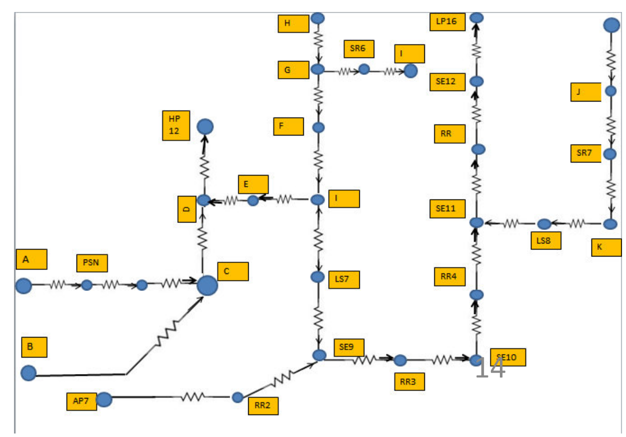
✓**The temperature contours of the compressor discs are affected by heat conduction from the shroud and by heat transfer to the air inside the cavity.**

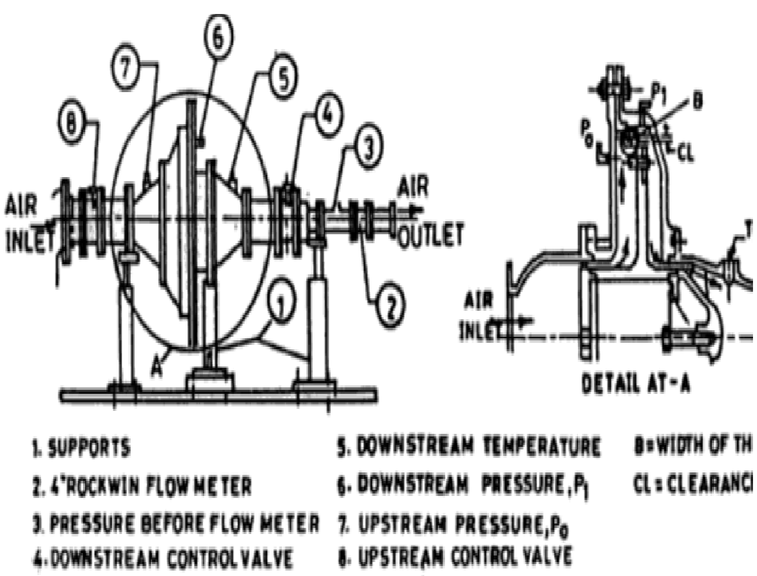
Typical velocity contours in seals



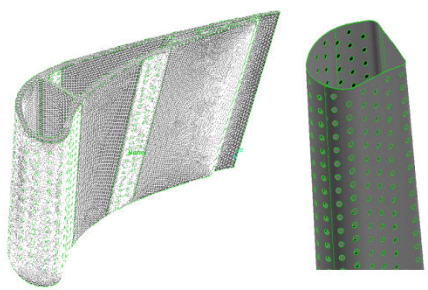


Net work analysis of impingement





Seal Testing Apparatus



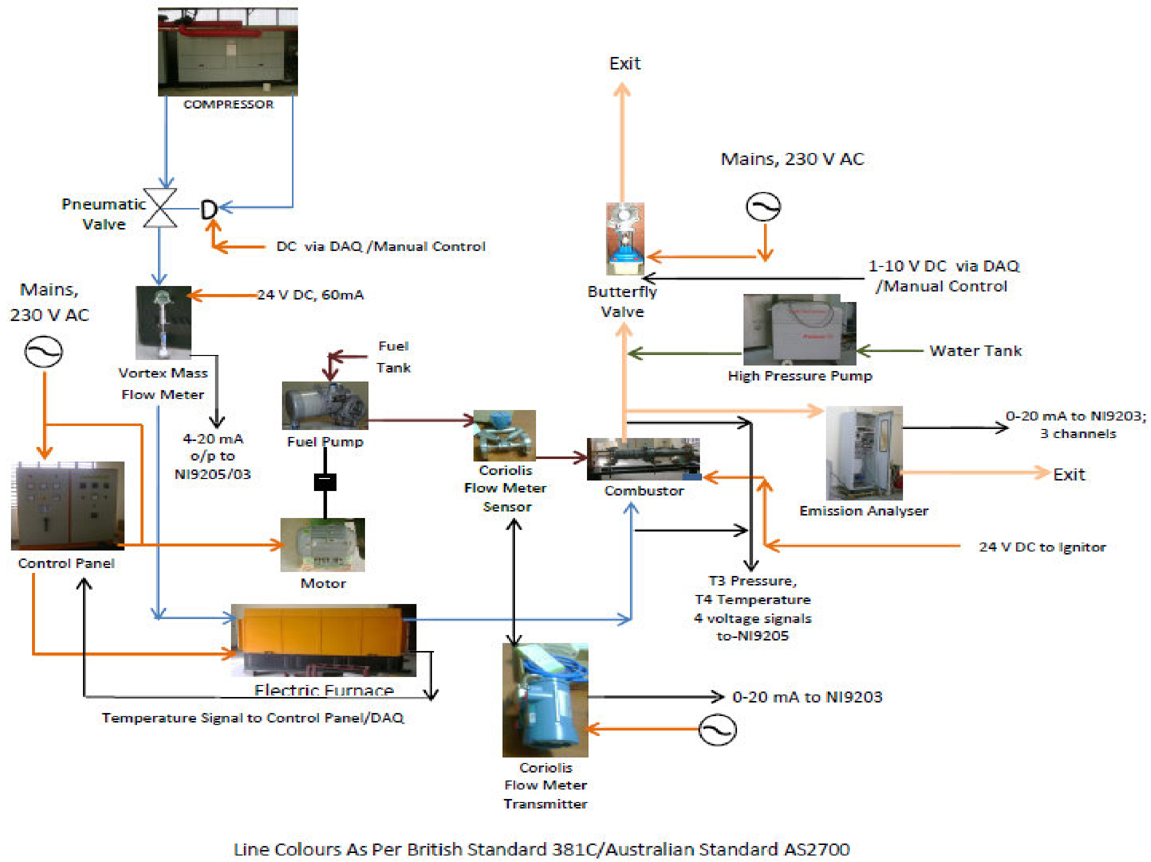
Indian Institute of Technology, Kanpur

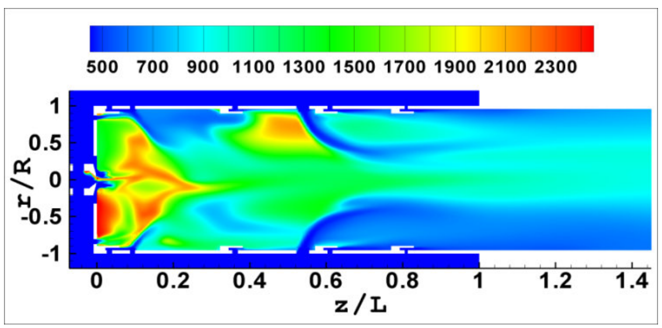
High Pressure Can Combustor Rig

- Pressure: upto 20 bar
- T3: upto 350 C
- Air Flow Rate: upto 0.5 kg/s
- Measurement of: ΔPb, T4, Emission, Soot

Current use:

Application of Biojet (from Jetropha and Camelina) fuel for Aviation: Combustion and Emission Studies

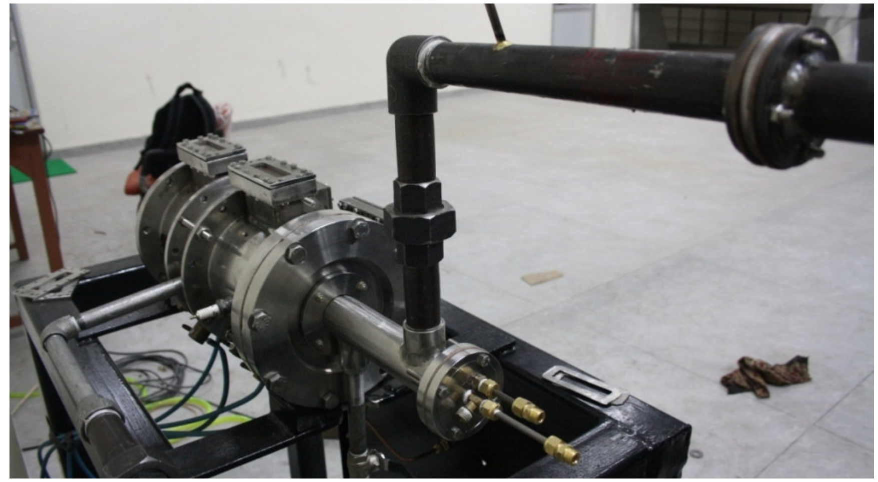




Simulated Temperature field

Atmospheric gas turbine combustor rig

- Separate primary, secondary, quenching and atomizing air supply
- Accurate metering and control of air and fuel (ATF) flows
- Optical access for PIV, LDV and PLIF measurements
- Tunable

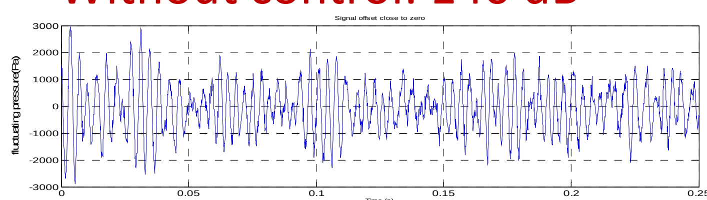


Current use:

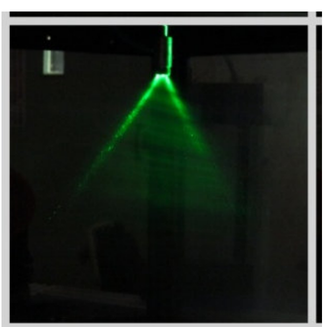
Active and Passive Control of Combustor Hooting

- Air-blast atomizer
- Swirl stabilized primary combustion

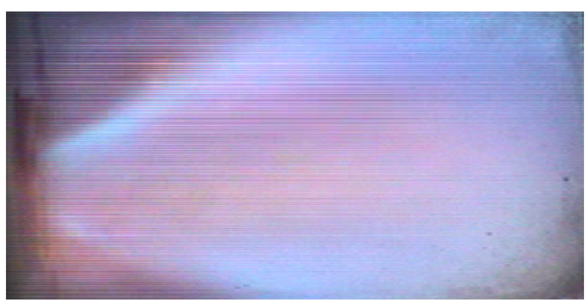
Without control: 140 dB



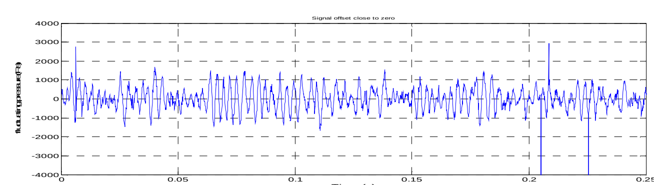
Fuel spray



Flame: Swirl no. 1



With control: 133 dB



Control: Modulation of atomizing air

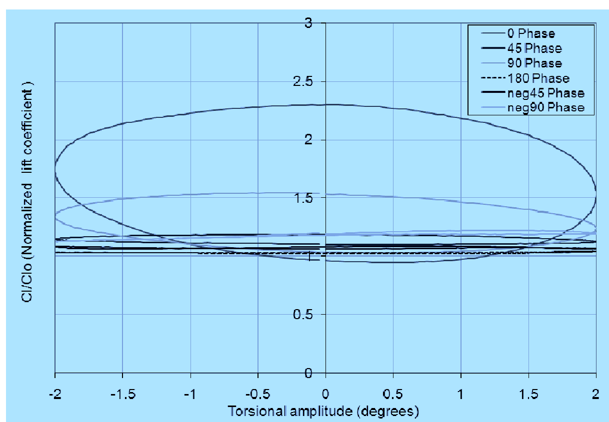
Linear Cascade Tunnel

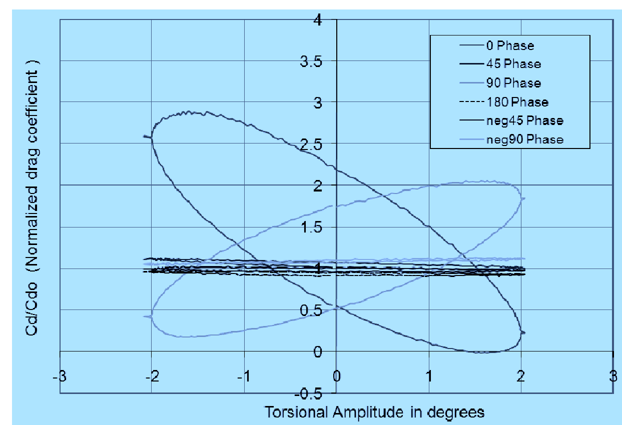
- Test section: 12” X 15”
- No. of blades: 5
- Maximum speed: 50 m/s

Current use:
Effect of Adjacent Blade Motion on the Aerodynamics of a Linear Cascade Blade

Earlier used for the secondary flow control in turbine cascade and stall control in compressor cascade

Lift and Drag variation with blade motion





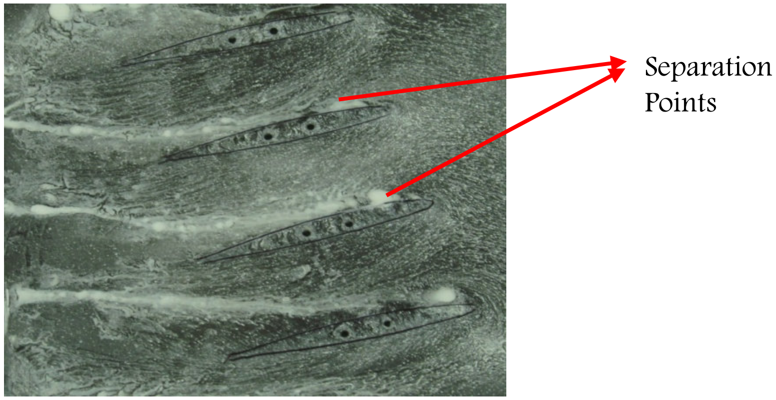
Small linear cascade tunnel

- Open-circuit low speed wind tunnel
- Centrifugal blower driven by a 10 hp (7.5 kW) electric motor
- Contraction section area ratio 16
- Test section of dimensions 150X150 mm.
- Inlet velocity adjusted by controlling the speed of the motor using a variable frequency speed controller

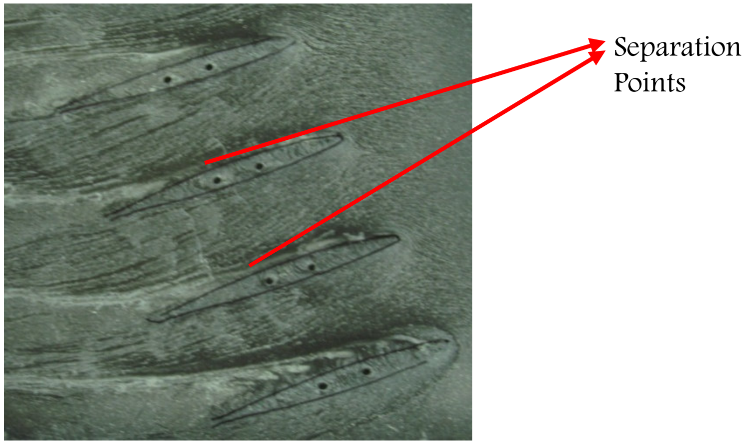
Current use:

Effects of Leading-Edge Geometry on Compressor Cascade Performance

Baseline

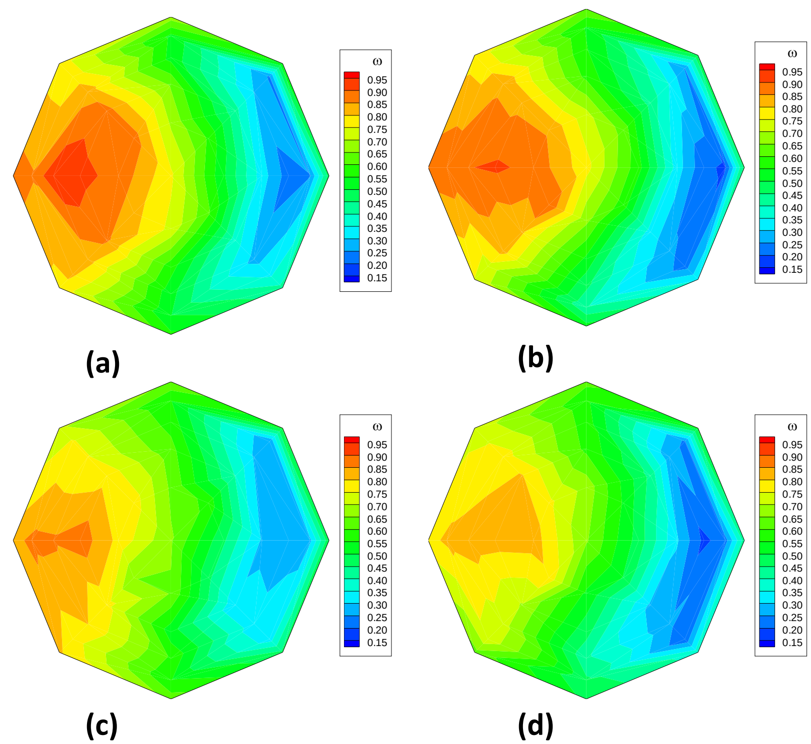


Modified LE: Delayed separation

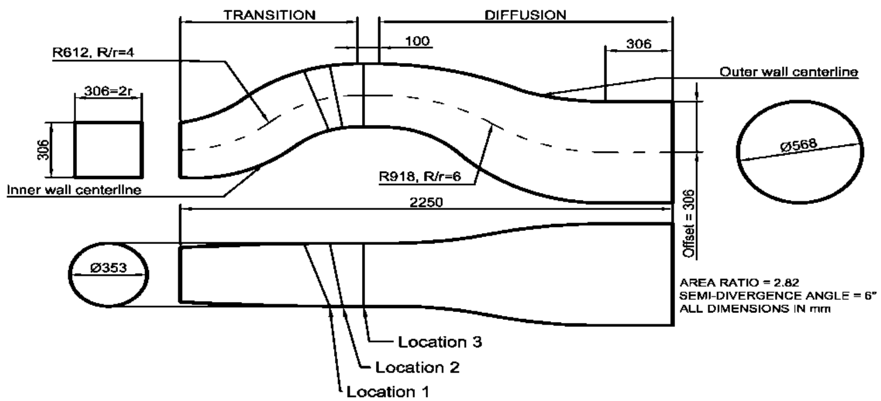


Intake Studies

- Serpentine ducts, separation control
- Flow Control
  - Vortex Generator Jets
  - Suction



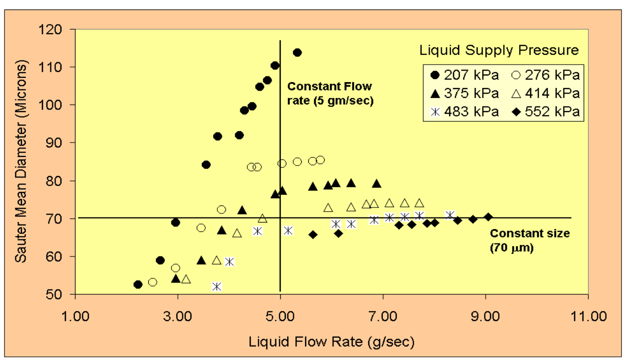
Total pressure loss coefficient contours for the cases (a) baseline, (b) VGJs at x/L = 0.33, (c) suction at x/L = 0.28, and (d) suction with VGJs



Liquid Atomization

- Pressure Swirl Atomizer
- Internally mixed twin-fluid swirl atomizer
- External air-assisted atomizer
- Airblast atomizer
- Effervescent Atomizer
- Electrostatic atomizer

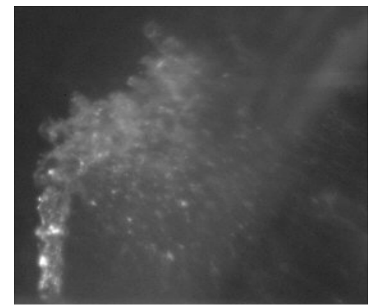
Controlled Atomization



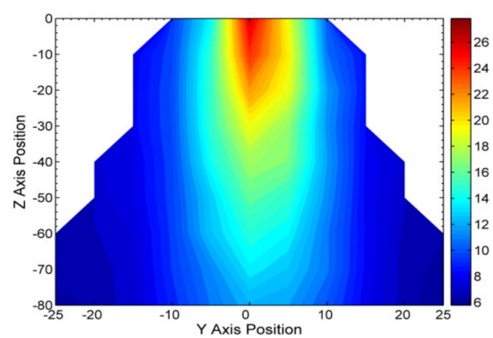
Spray Chamber

Design Conditions:
500 psi Pressure
450 C Temperature
30 cm Diameter
120 cm Length
3 windows for PDPA measurements
Pressure regulated by a valve

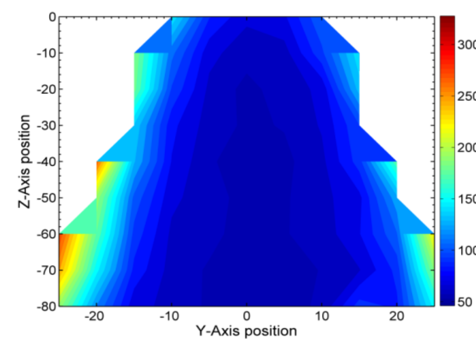
Jet breakup in cross flow



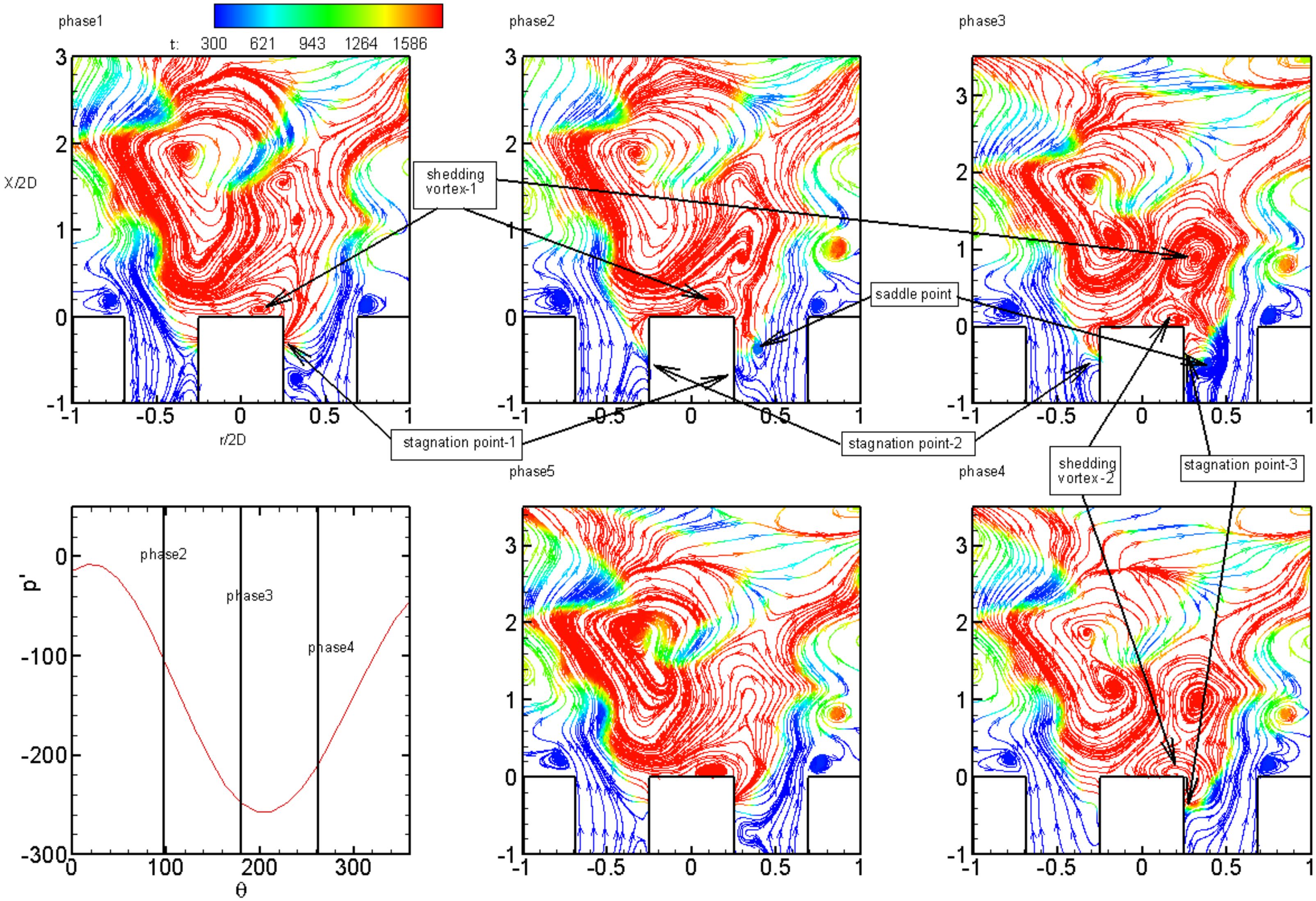
Droplet Velocity



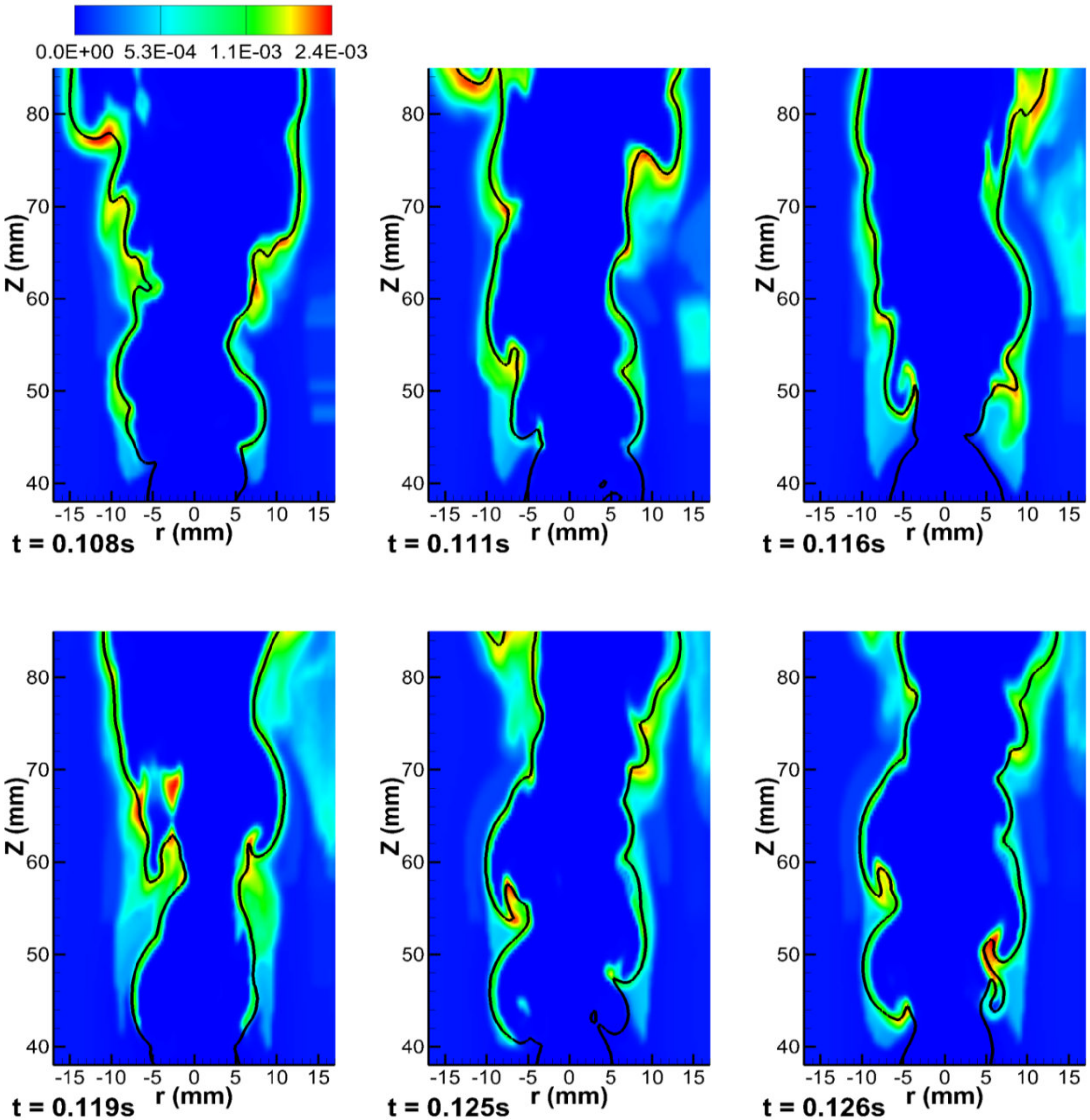
SMD



LES of Premixed combustion-during flashback cycle



LES of Diffusion flame- Lift-off height prediction



- Most of the reaction occurs along the stoichiometric line
- Location where the mass fraction of OH is more than 1e-03 corresponds to an ignition event
- Lift-off height – 46mm

Figure. Instantaneous OH mass fraction distribution for the case of Re_{jet} = 4100 at various time instants. Isoline: Stoichiometric mixture fraction line ($\xi_{st} = 0.07$)

Soot prediction of natural gas flames

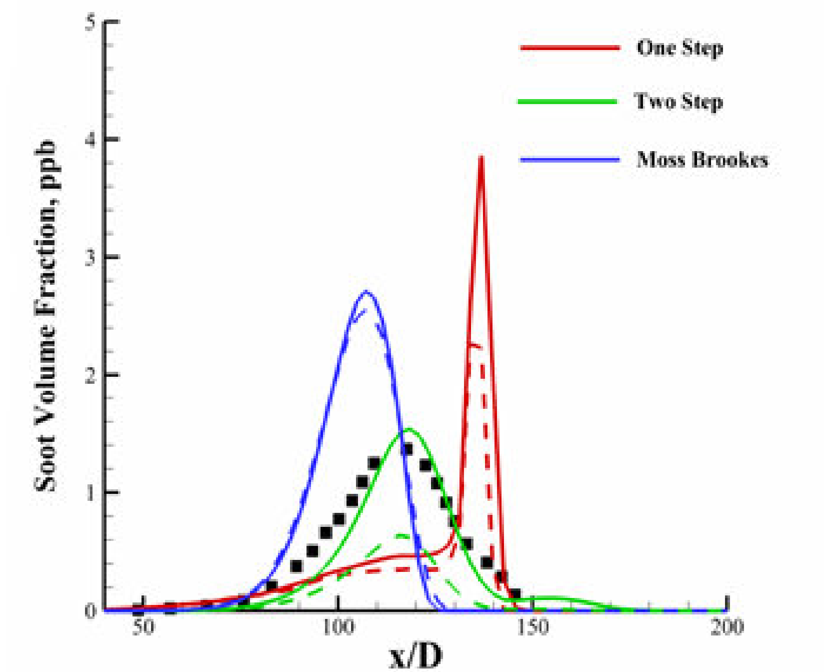


Figure: AXIAL PROFILE OF SOOT VOLUME FRACTION: SOLID LINES ARE WITHOUT RADIATION, DASHED LINES ARE WITH RADIATION AND SYMBOLS ARE MEASUREMENTS

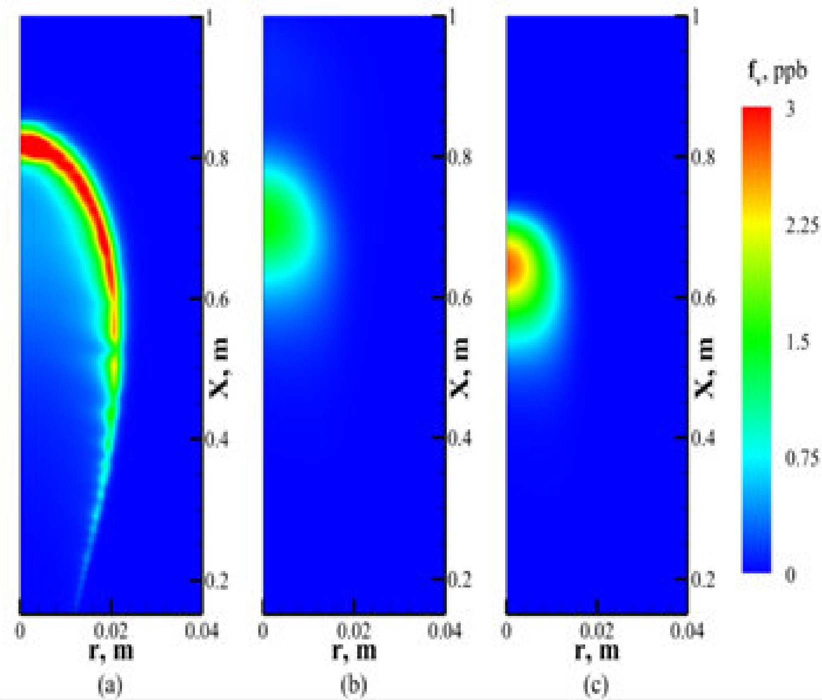


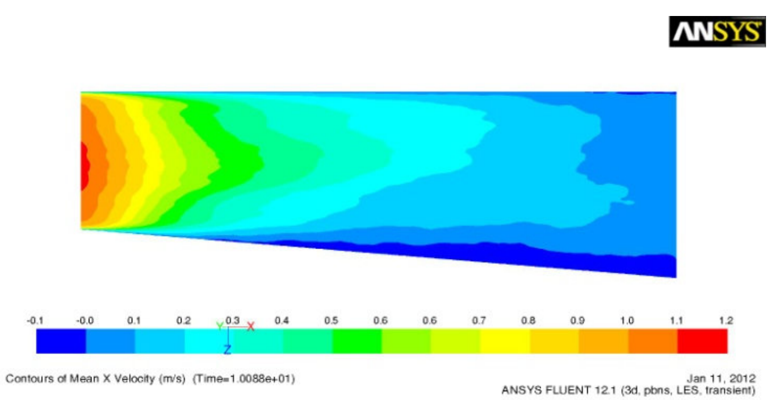
Figure : CONTOUR OF SOOT VOLUME FRACTION. SHOWING (a) ONE STEP, (b) TWO STEP AND (c) MOSS BROOKES

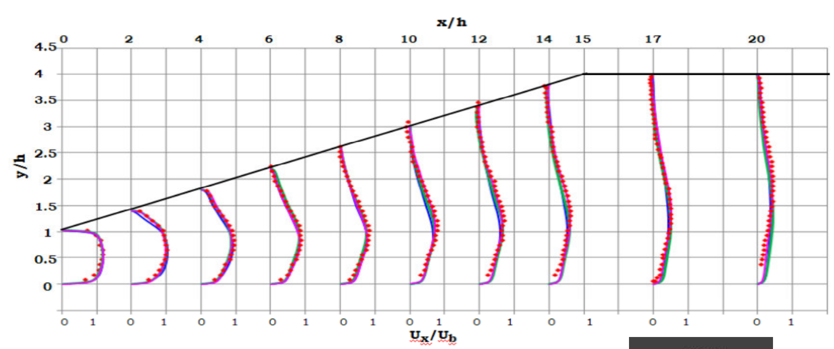
Large Eddy Simulation for Gas Turbines

- Department of Aerospace Engineering
- Indian Institute of Science Bangalore

Separated flow in dump diffuser

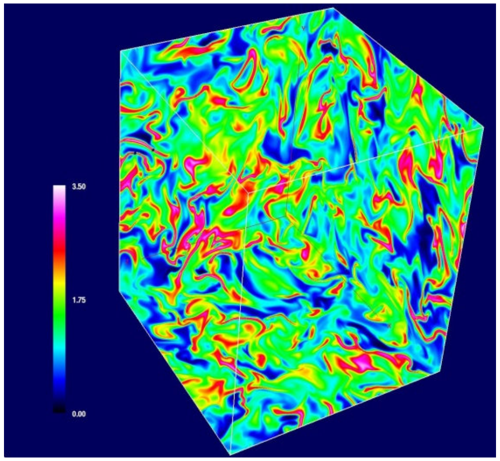
- RANS and LES of benchmark flows
- 2-D Obi diffuser – RANS fails to predict separation, or significantly wrong extent of bubble size; LES is accurate
- 3-D Cherry diffuser – RANS predicts separation from *wrong* wall. LES predicts correct wall. LES solution is *quantitatively close if* upstream duct flow is also from a correct turbulent flow (LES). ***GTIndia 2012-9555***. **Figures show reverse flow region (left) & velocity profiles (right)**

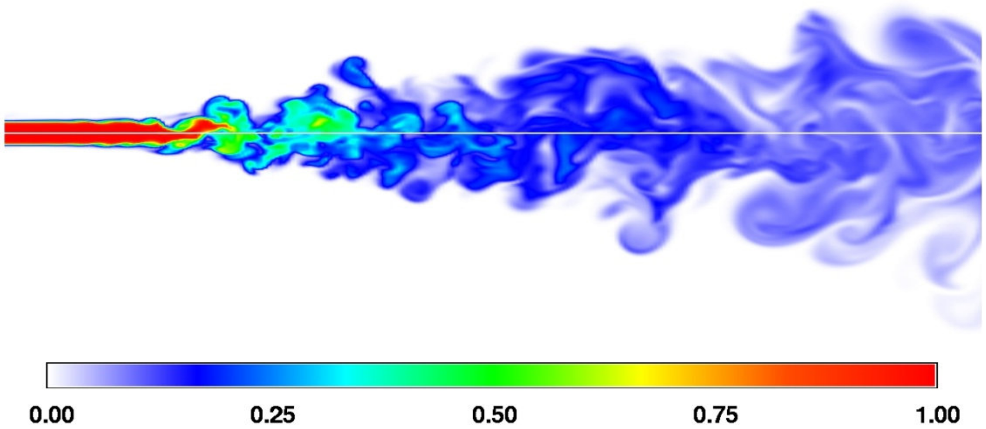




LES of non-premixed flames

- Tests of *LES by explicit filtering* for combustion.
- (*a*) Fuel/oxidizer layers in homogenous turbulence field,   (*b*) SANDIA flame D.
- **Figures show flames in homogenous turbulence after fuel/oxidizer layers have mixed (left) and SANDIA flame mixture fraction (right).**

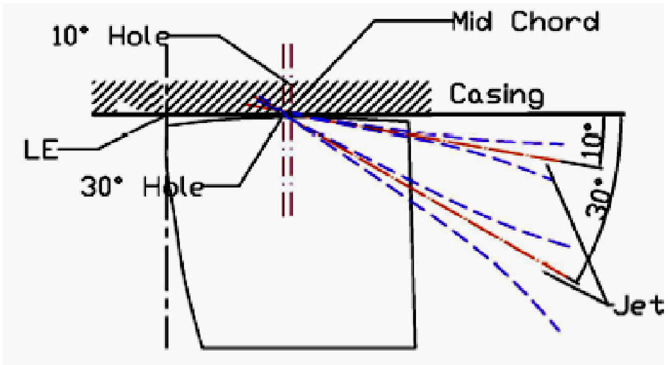


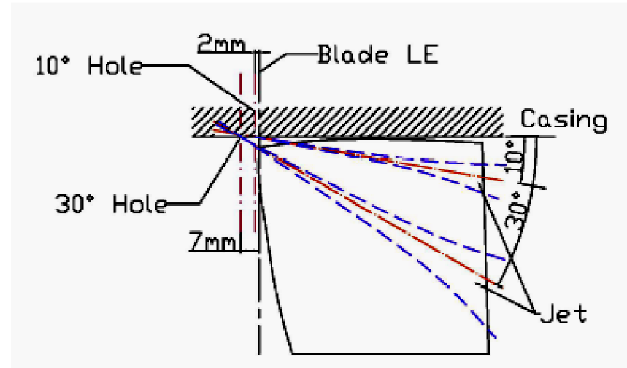


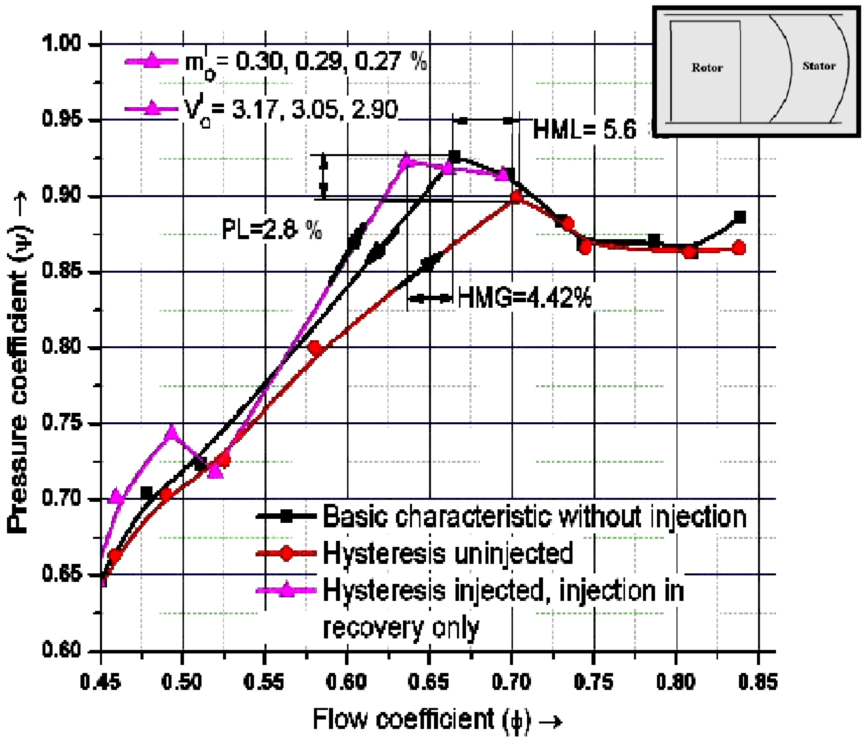
Indian Institute of Technology Bombay

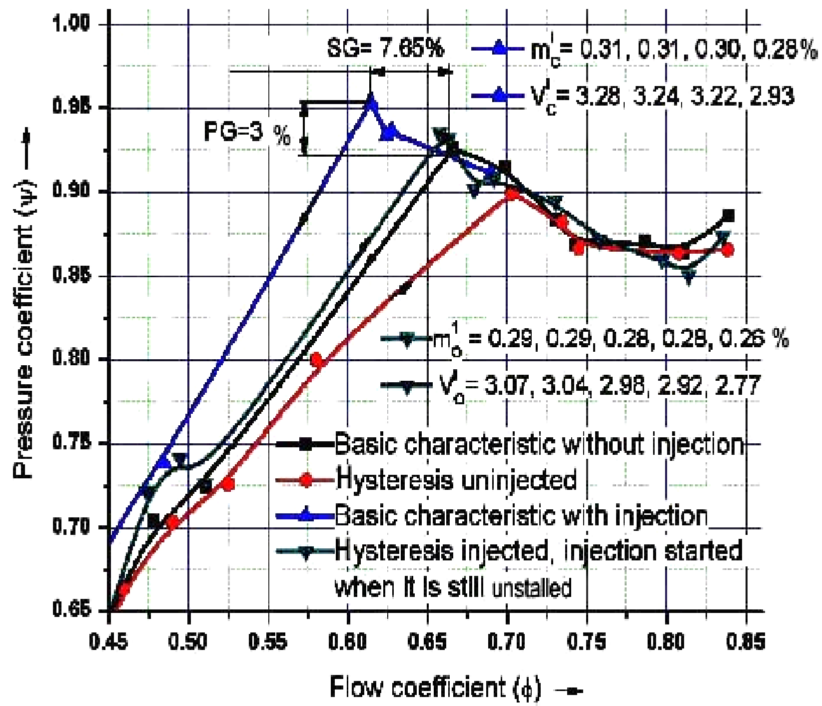
Research work in IIT, Bombay
On
Axial Compressor, Turbine, Intake - Aerodynamics, Combustion and Hypersonic Intake

Tip Flow Control in Axial Compressors (Exptl work)



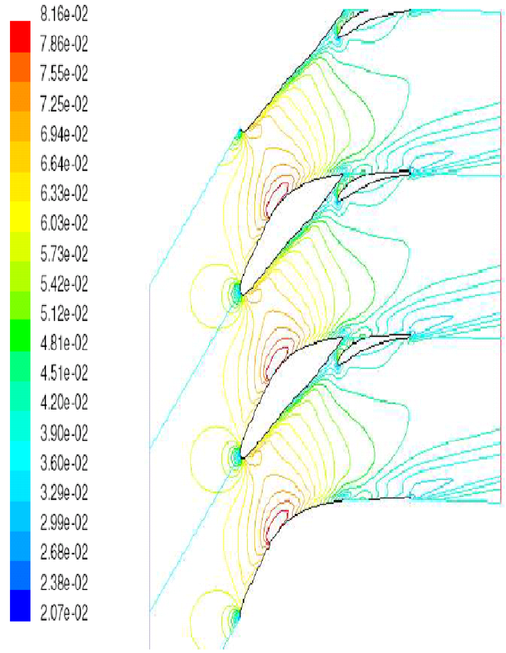


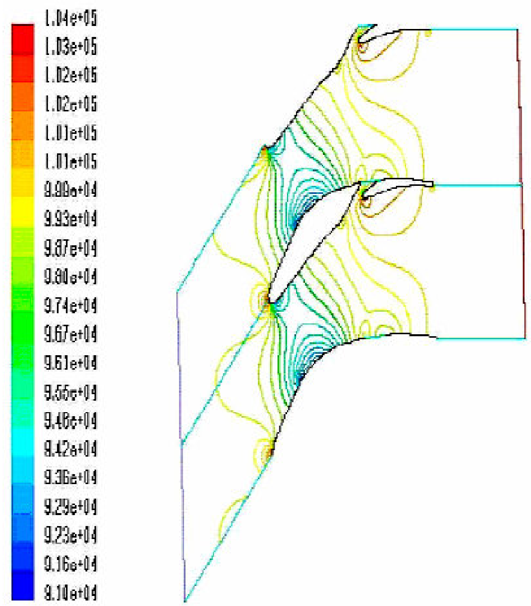




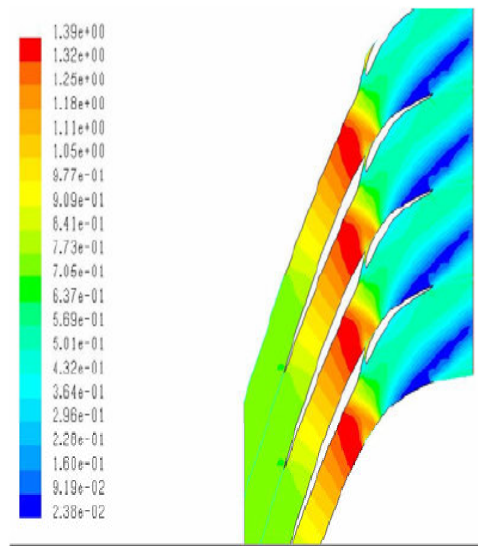
Variable camber blades : Exptl & CFD

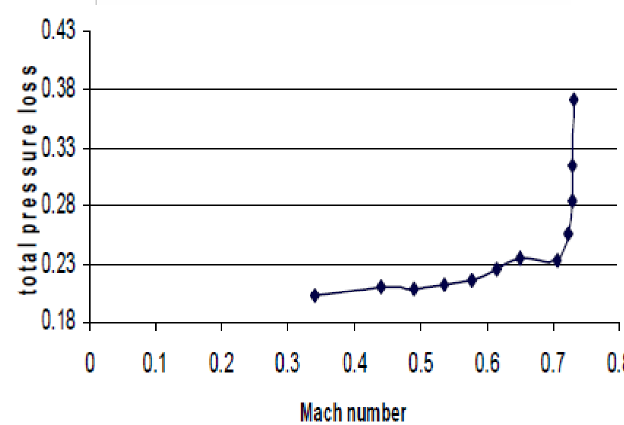
CFD



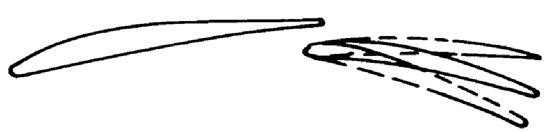


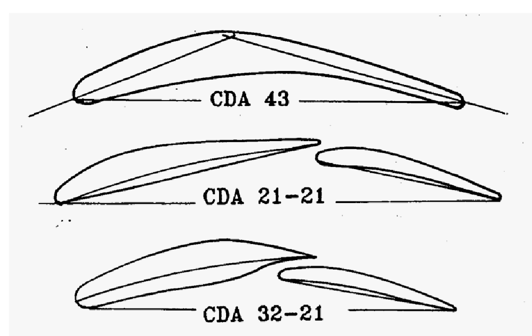
Supersonic Analysis (CFD)





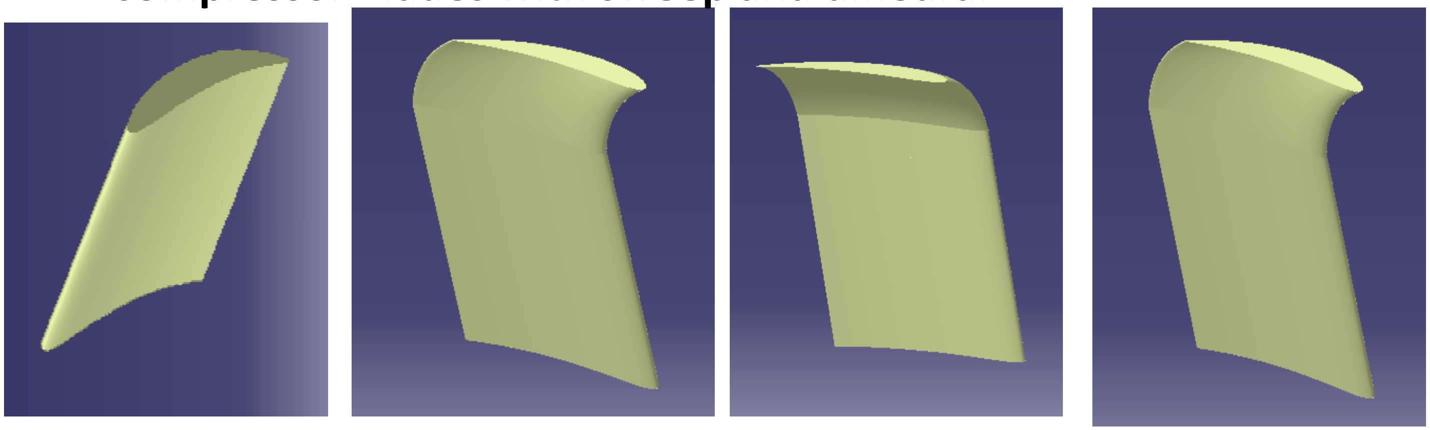
Subsonic Analysis (Exptl)



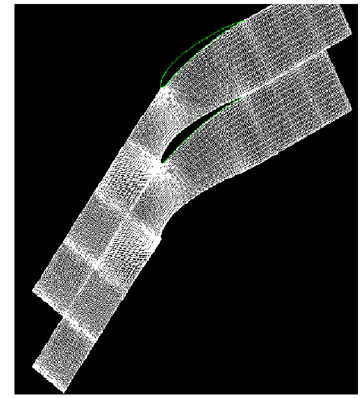


Cascade Studies

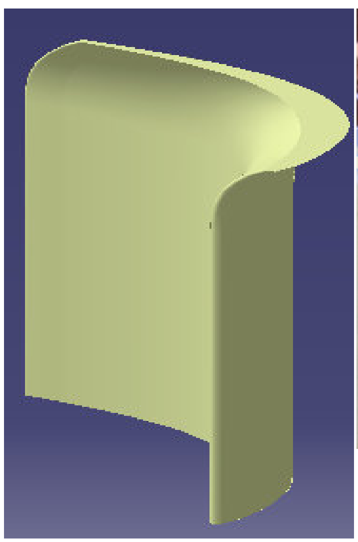
Compressor Blades with sweep and dihedral

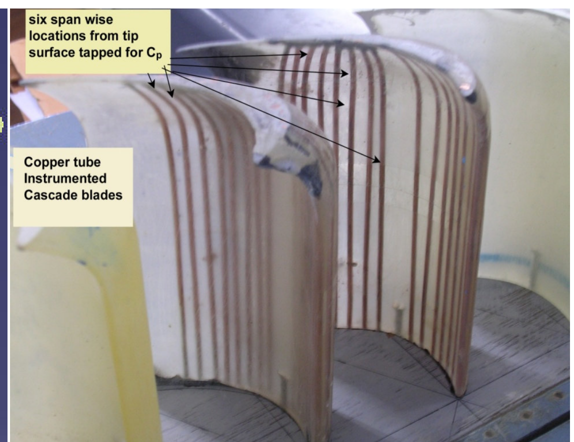


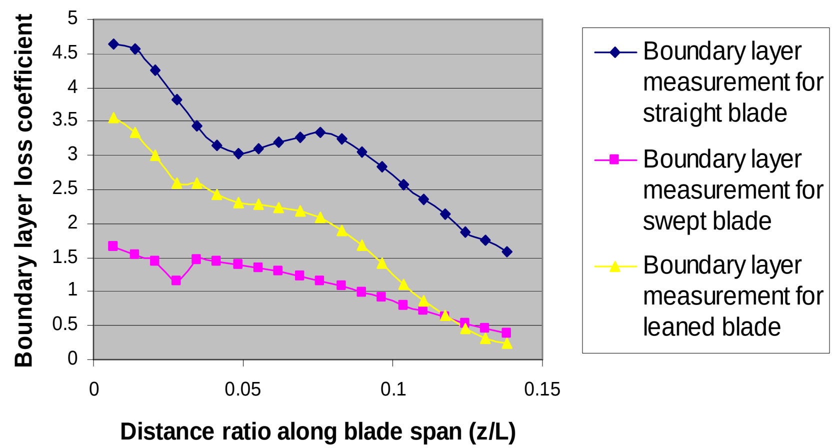
CFD-MISES



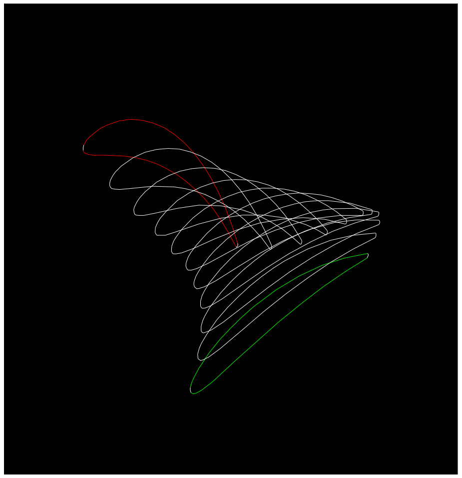
Turbine Blades with dihedral





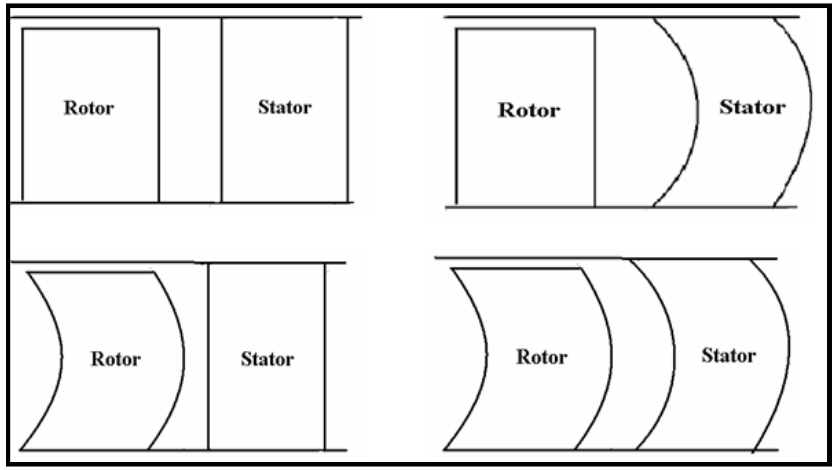


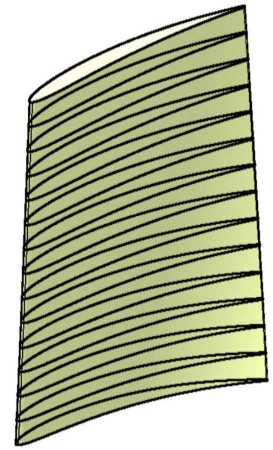
Design and Experimental study of swept blades in Axial Compressor



Swept stator 3-D design

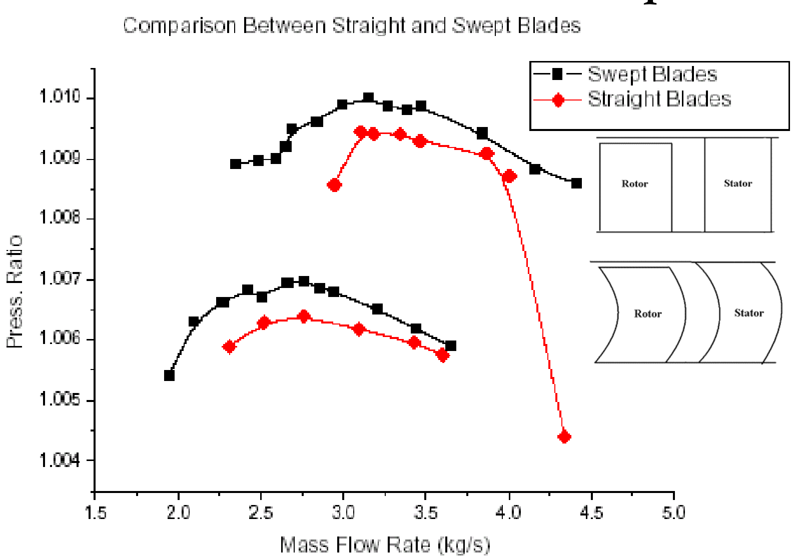
Various combinations of blades tested

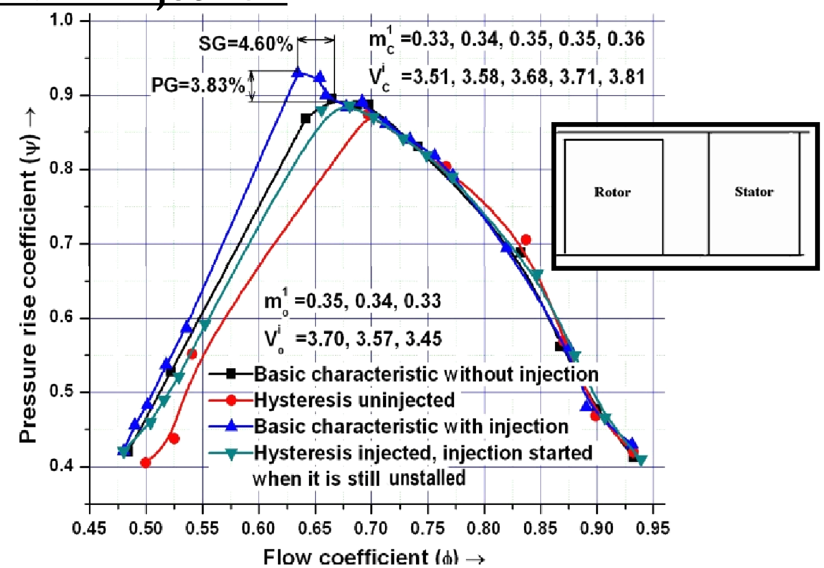




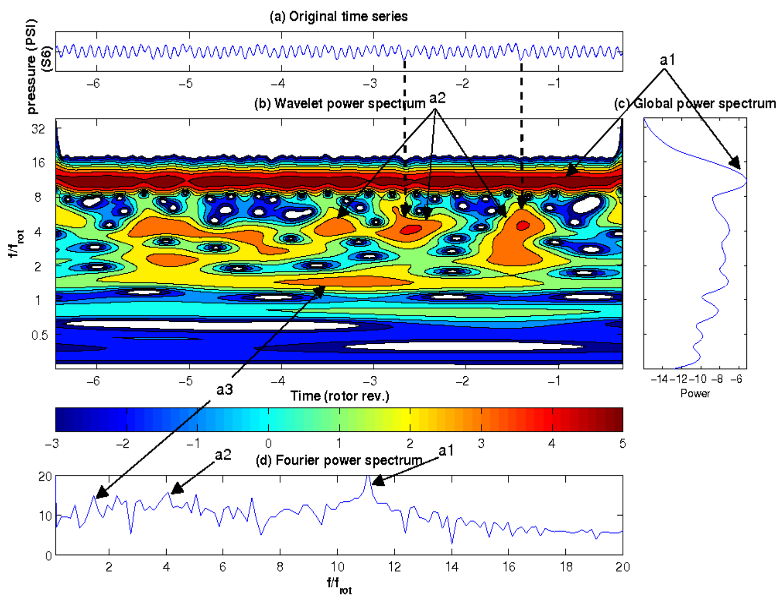
Rotor blade design

Enhanced performance with injection

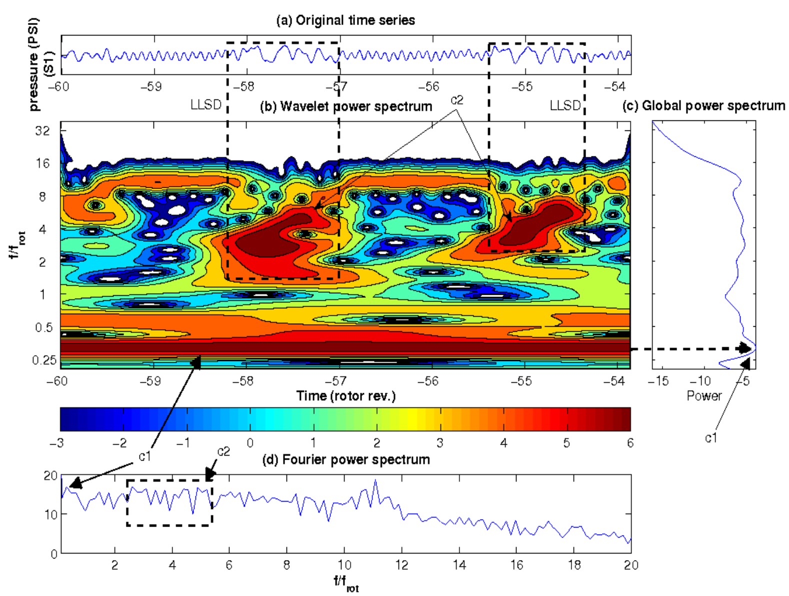




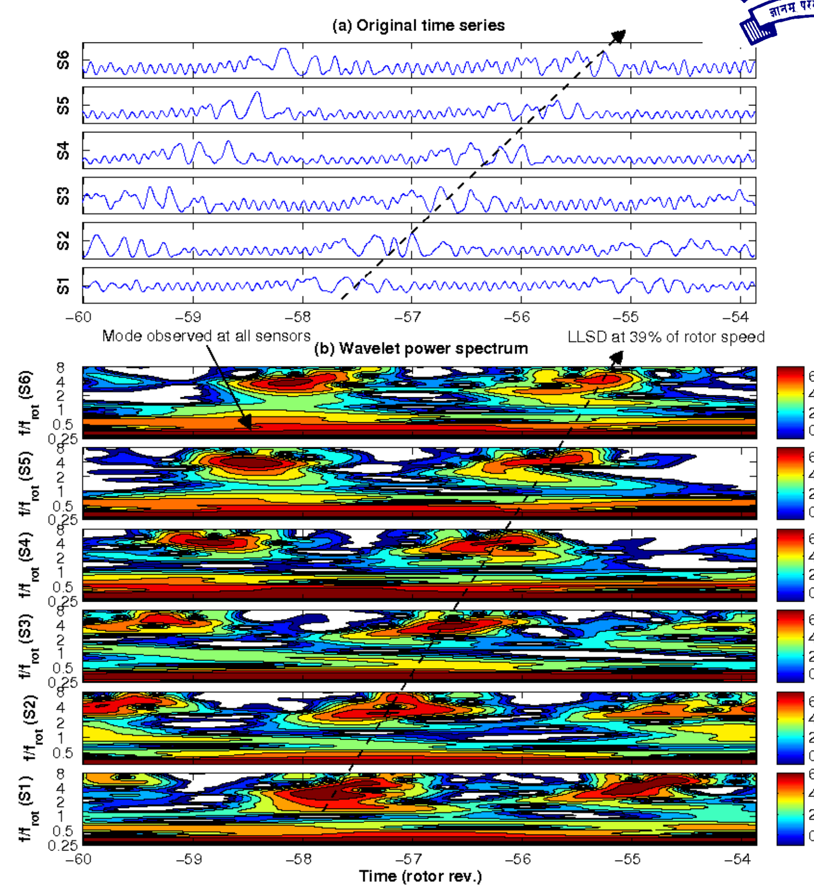
Distortion Analysis in Axial Compressor [Experimental]



(a)



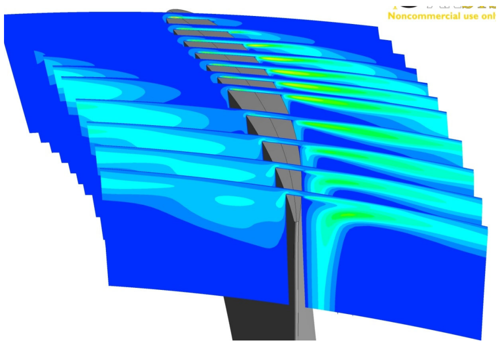
(b)



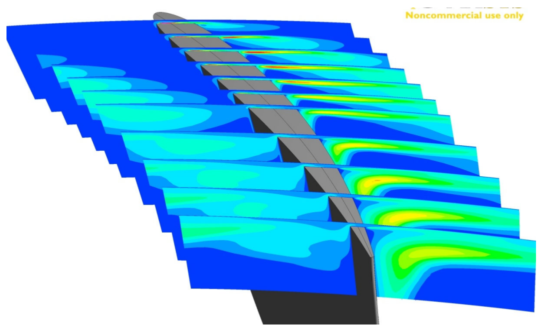
(c)

With (a) Clean, (b) Co-rotating and
(c) Contra-rotating inlet distortions

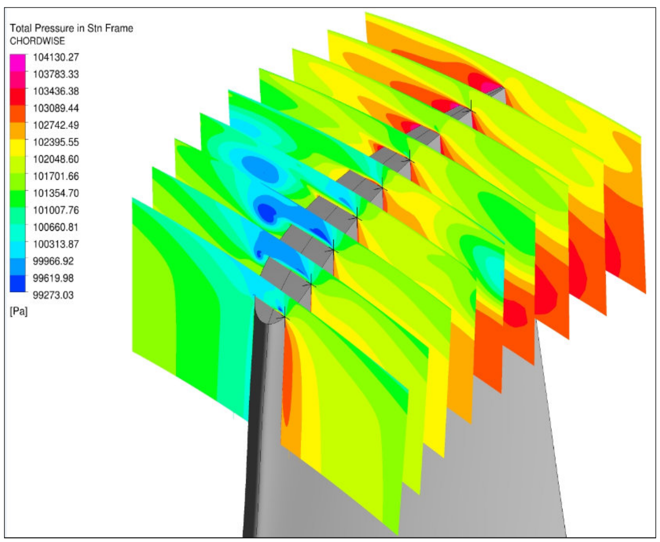
Rotor Tip Flow Analysis with Tip Gap Variation (CFD+ Exp)]



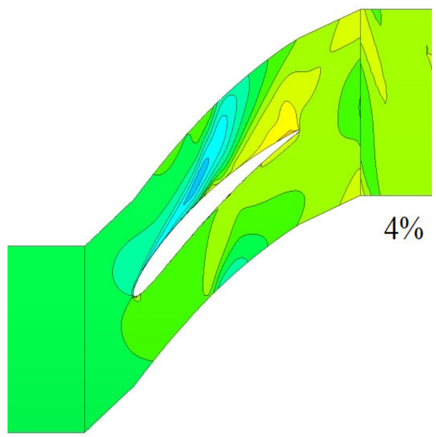
Design point Tip Flow



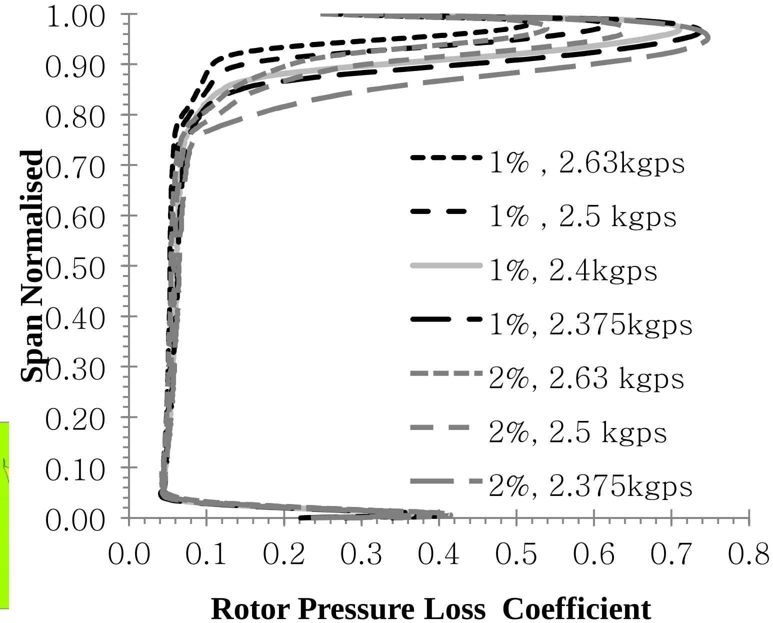
Near Stall Tip Flow

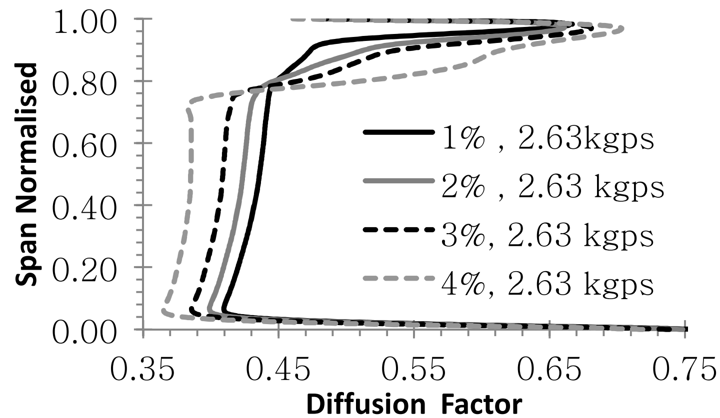


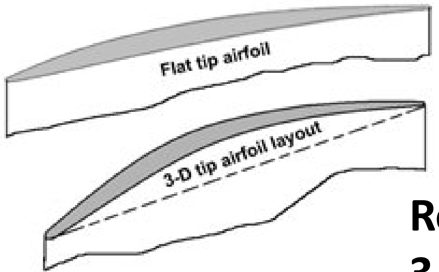
Flow across tip for 3% tip gap



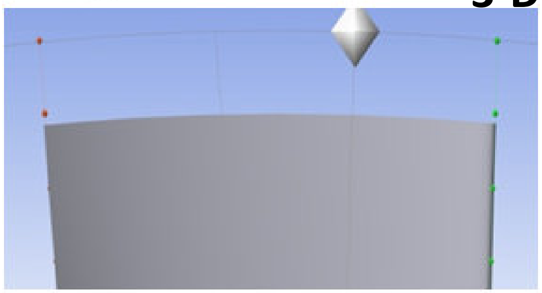
Tip airfoil flow
@ 4% tip gap

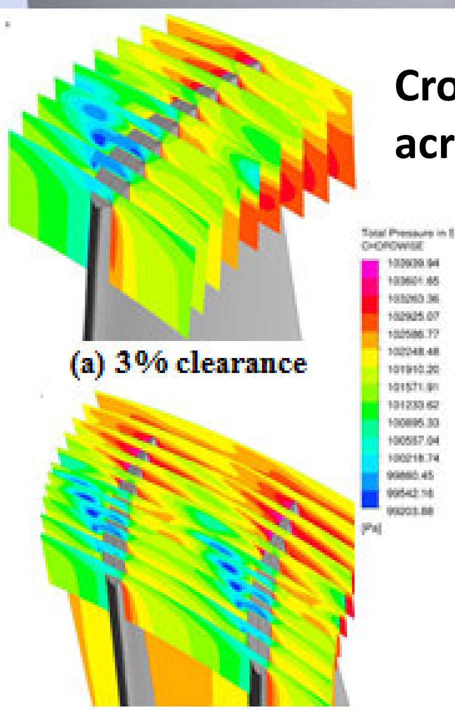






Round tip blade with
3-D airfoils – CFD studies

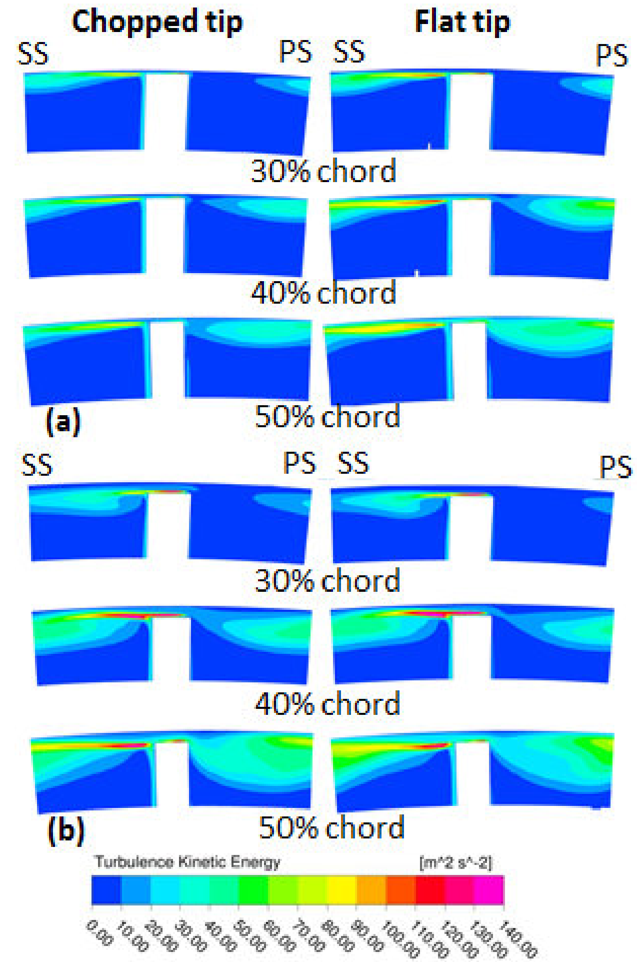




(a) 3% clearance

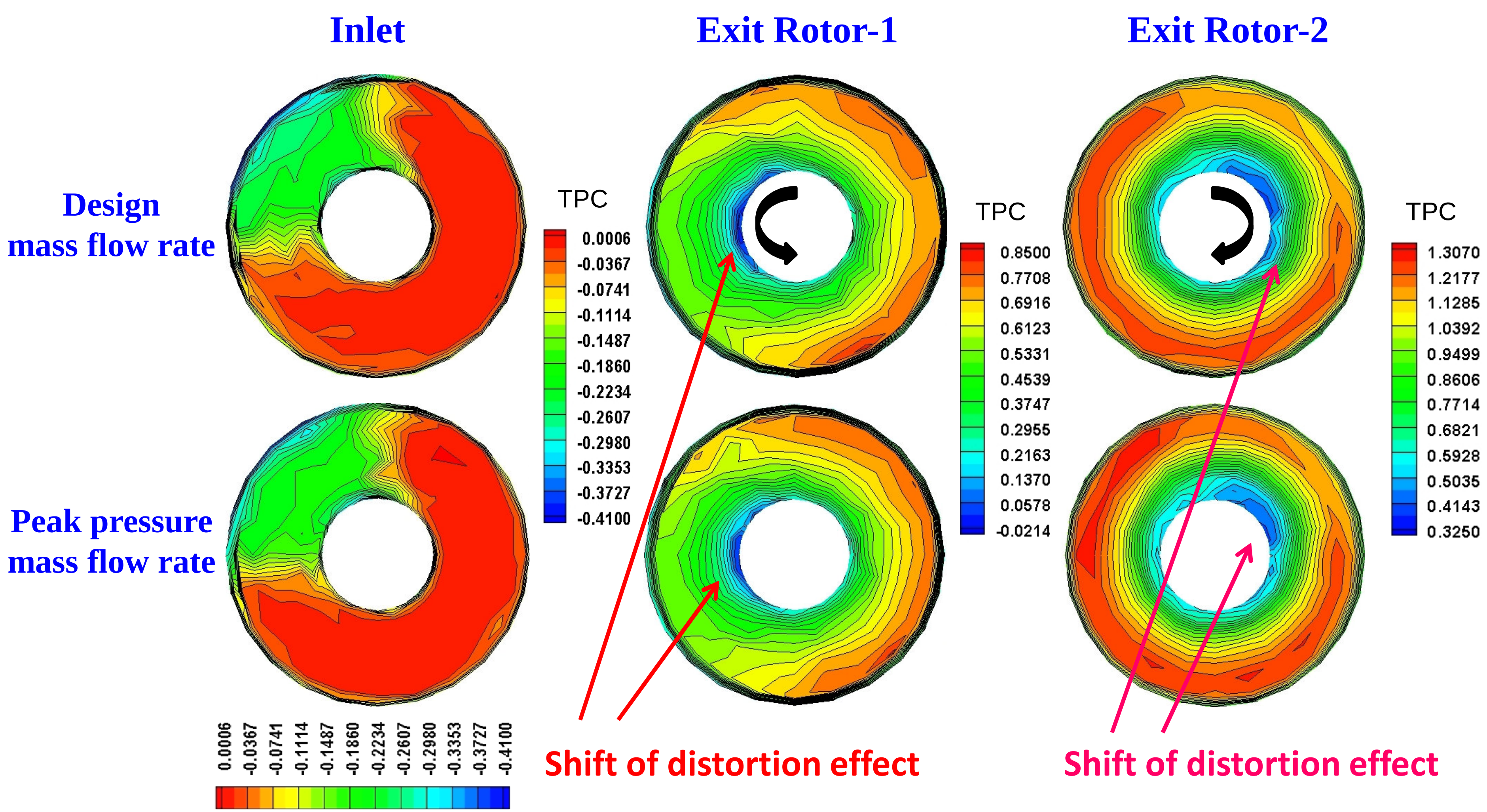
(b) 4% clearance

Cross flow vortex migration across the rotor tip

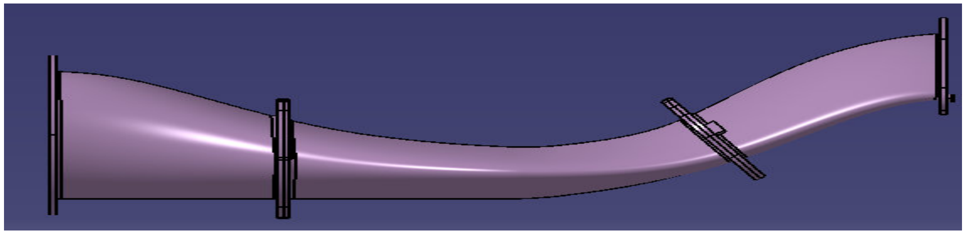


Tip cross flow TKE
at (a) 1% and (b) 3% span tip gap
at Design point

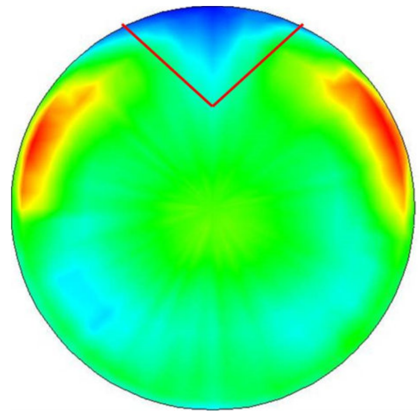
Propagation of Inflow Distortion in a Contra-rotating Axial Fan



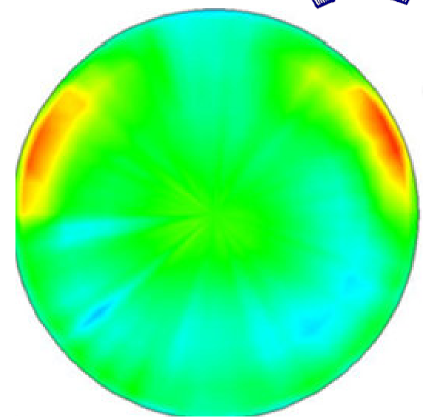
Active and Passive Flow Control in High Turning Ducts/Diffusers



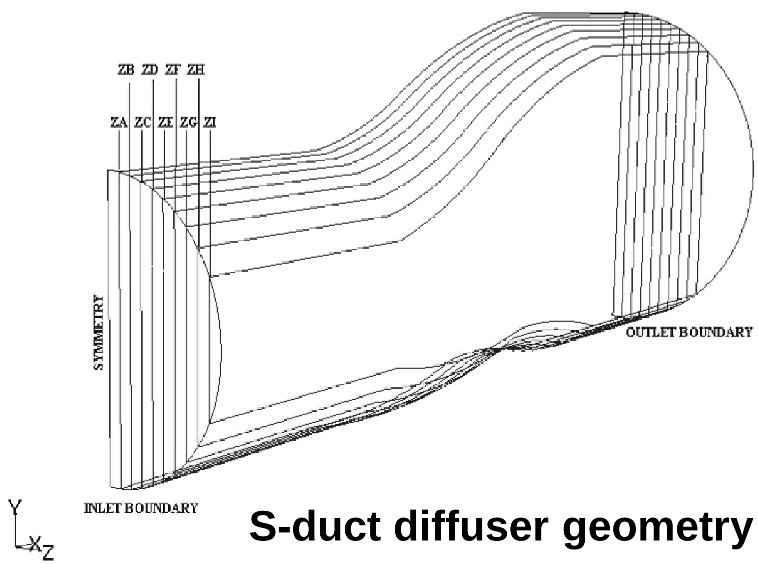
High turning diffuser geometry



Bare duct,
High AIP distortion

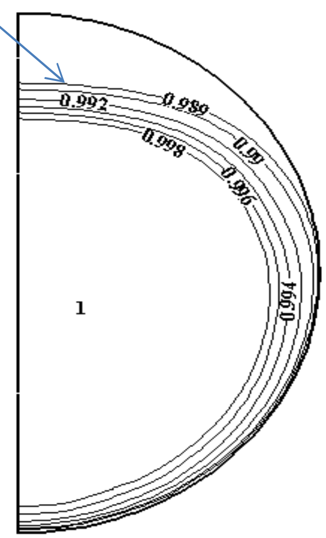


Duct with flow control, Low AIP distortion

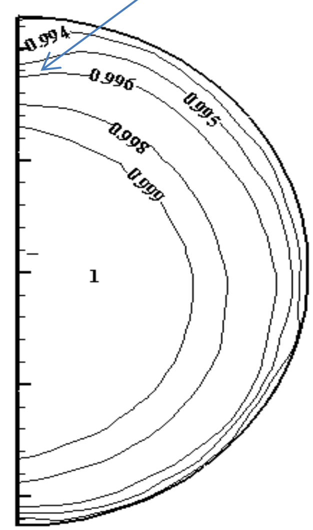


S-duct diffuser geometry

Higher total pressure loss

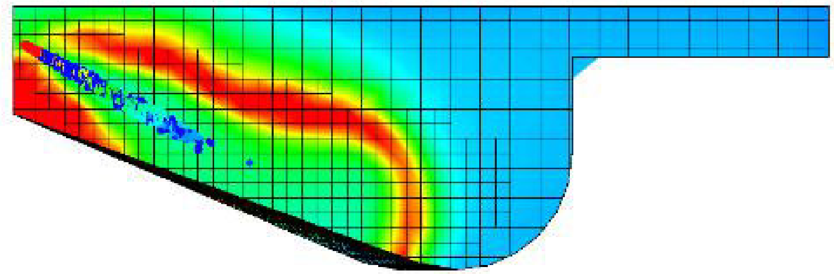


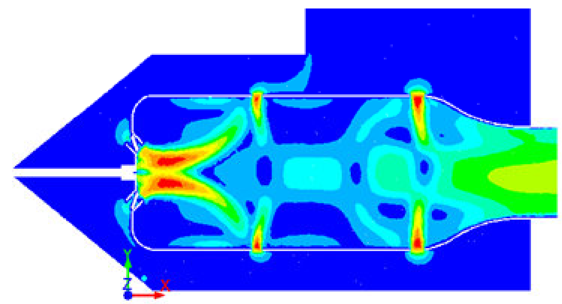
Improved total pressure distribution

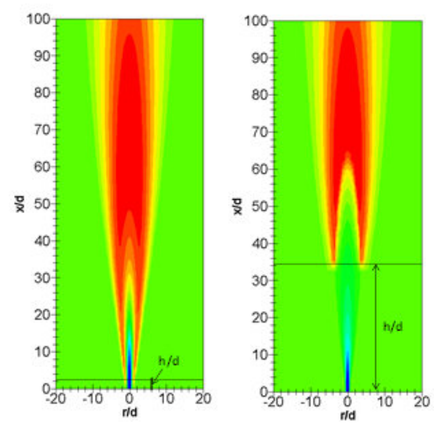


Computational **Combustion**

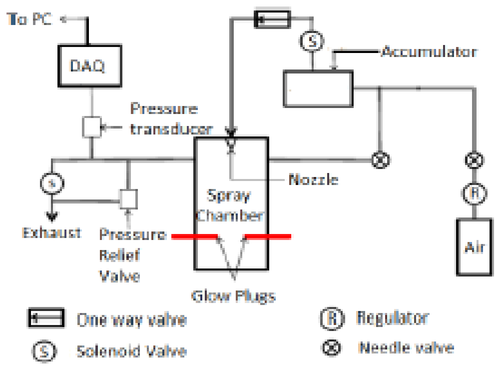
- Achieving ultra low emissions in to meet the stringent emission regulations.
- Attention is mainly focused on getting a stable combustion for a wide range of A:F ratios.
- Simulation of partially premixed combustion. Case study of a hydro-carbon lifted flame..

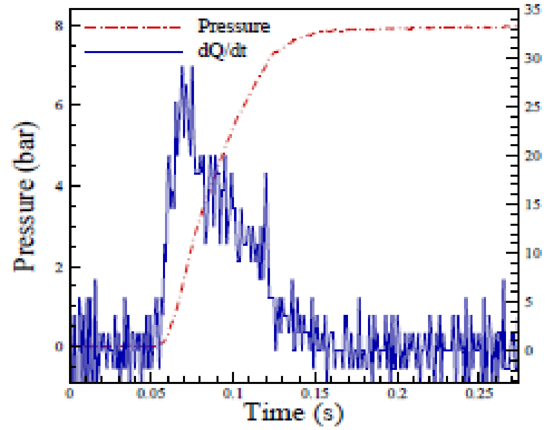


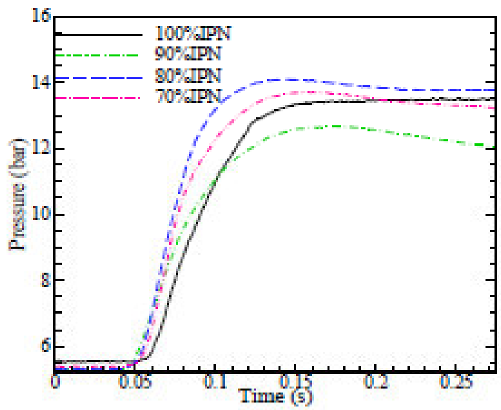


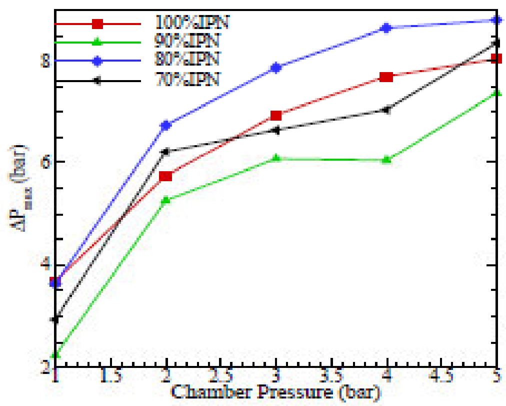


Spray Combustion



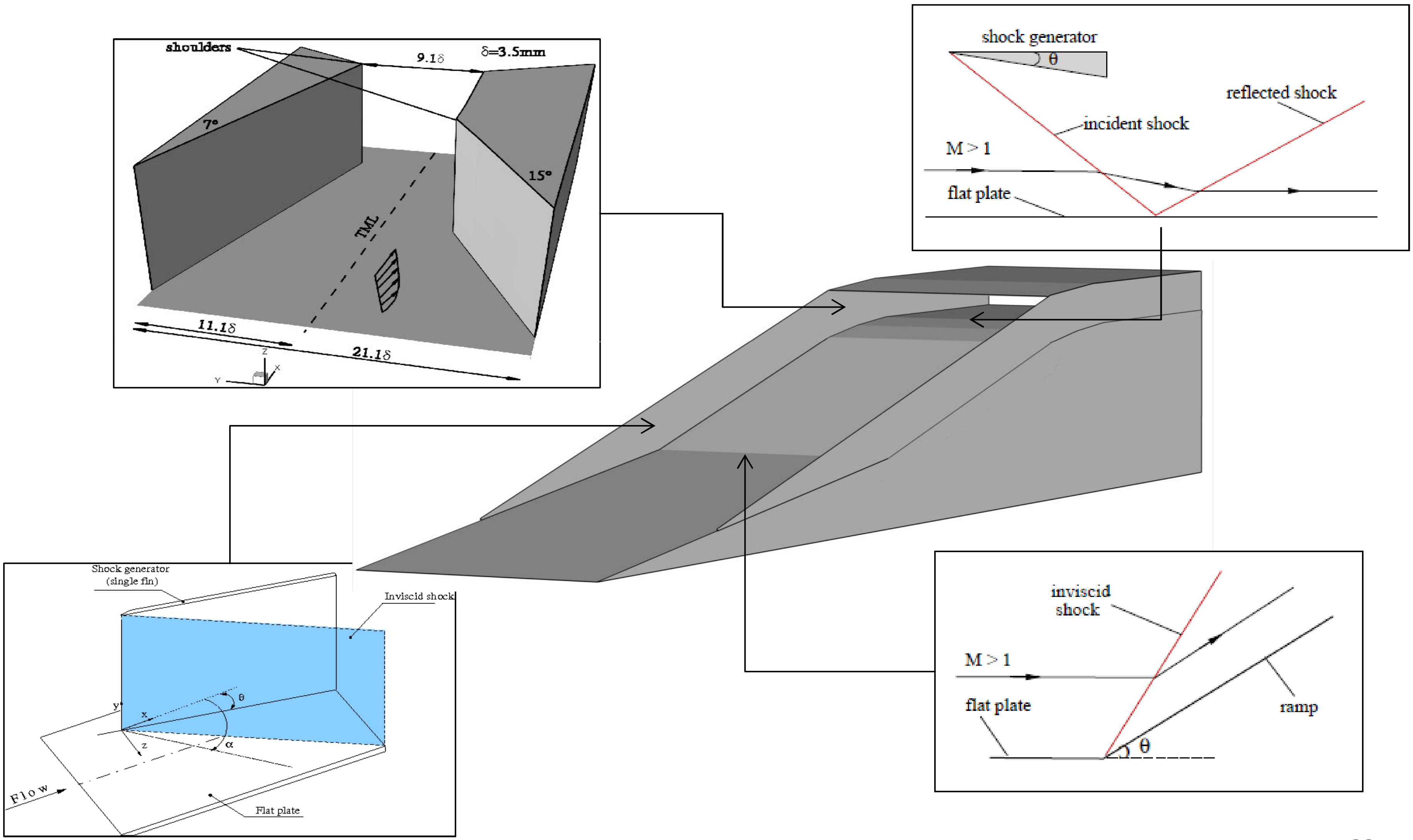




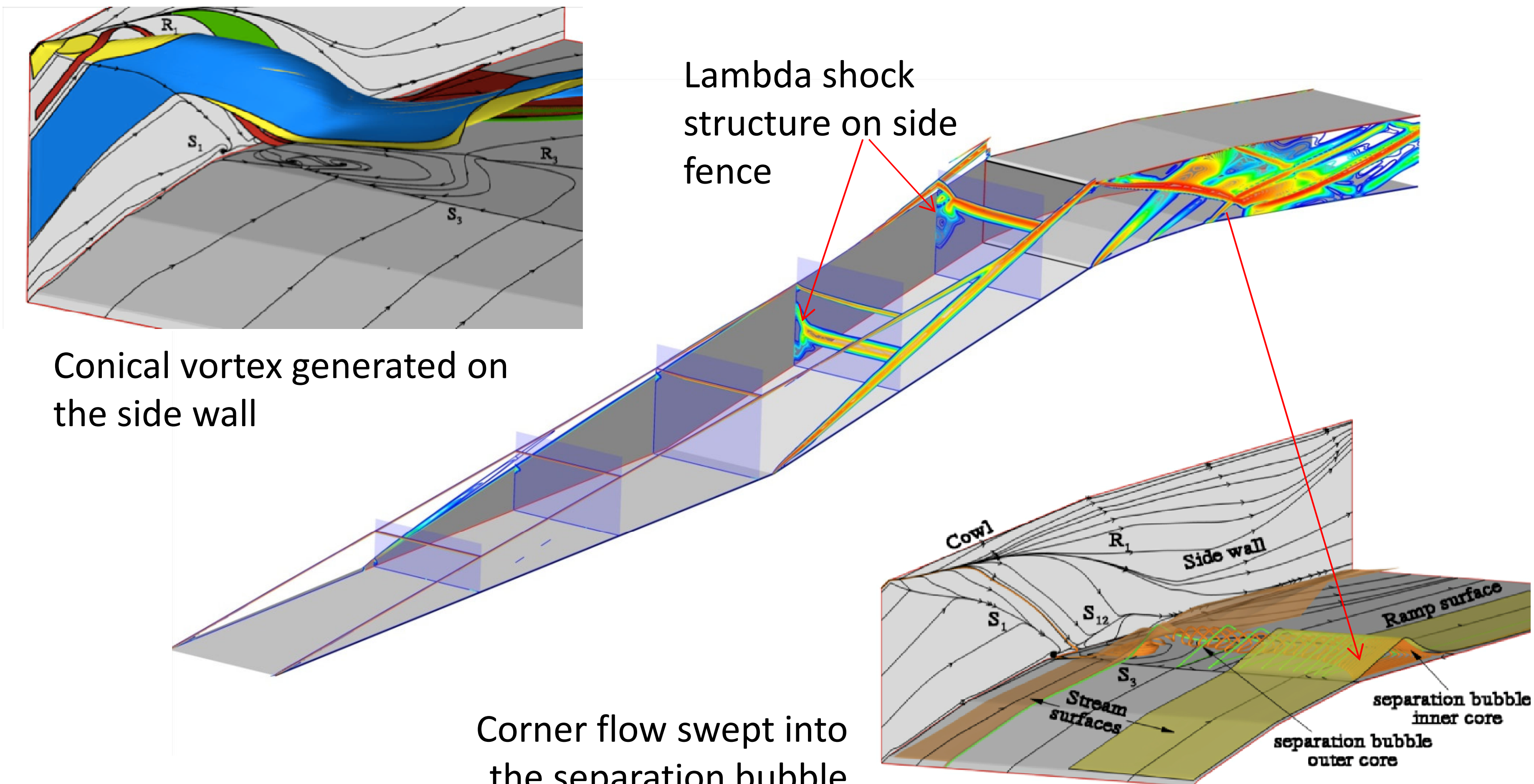


Lean Premixed GT combustors

Shock-boundary layer interaction in a scramjet inlet – IIT, Bombay



Three-dimensional flow field analysis using in-house CFD code – IIT, Bombay



Conical vortex generated on the side wall

Lambda shock structure on side fence

Corner flow swept into the separation bubble

Concluding Comments

India at Crossroad

- A large number of international collaborative research projects have been completed in India, there are areas of improvement in project management.
- Indian laws on information protection, secrecy, and copyright protection require further upgrading
- USA sanction on various areas of technology apply
- Most of the measuring instruments need to be imported from US, Germany, Denmark or Japan.
- Running costs of the personnel is low and shall remain internationally competitive for many years.
- Fabrication cost of rigs is also very competitive.

- Indian Institutes are not encumbered by any political framework

- Most Indian Institutes work in a free democratic management set up

- Methods for signing international agreements, IP sharing, patenting, NDAs and MOUs are operational in all the Institutes/ Labs

- Visits of Scientists and Technologists from various countries is easily facilitated within the Institute

- Exchange of faculty, technologists/ scientists and students are routinely facilitated by the Institute/ Lab

India is poised for global research collaboration

Thank You

ISABE 2013
21st ISABE Conference
September 9-13, 2013 Busan, Korea

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY
ज्ञानम् परमम् ध्येयम्